NATIONAL BUREAU OF STANDARDS REPORT

9699

SPECIAL STUDY

OF

NBS FACILITIES REQUIRED FOR FUTURE PROGRAMS IN

CLIMATIC EXPOSURE, ARCHITECTURAL ACOUSTICS, AND FIRE RESEARCH

Prepared for

The Institute for Applied Technology

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C., 20234.

[2] Located at Boulder, Colorado, 80302.

[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

NATIONAL BUREAU OF STANDARDS REPORT

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Prepared for
The Institute for Applied Technology

by an
Ad Hoc Task Group
P. R. Achenbach, Building Research Division
Chairman

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BY

IAT Ad Hoc Task Group

CHAPTER 1

Introduction

1. History of Facilities Planning

In May 1965 the staff of the Building Research Division prepared a first draft of a report on Long-Range Planning, at the request of the NAS-NRC Advisory Panel for that Division. This report described the technical programs that should be implemented during the next ten years to provide some of the major kinds of scientific information required by the building industry and the nation, and identified eight facilities, some comprising more than one building, needed to carry out this program. The need for long-range program planning was stimulated by the impending move of the Building Research Division to the new laboratories in Gaithersburg in 1966 and by the new emphasis on applied research which accompanied the creation of the Institute for Applied Technology as one of four major organizational units of the National Bureau of Standards.

Planning of new facilities for fire research began in 1958 when a very modest facility was scheduled to be among the first to be constructed at the Gaithersburg site. However, these plans were deferred when a more careful analysis of the program requirements showed that the estimated cost could not be accommodated in the initially approved cost of developing the Gaithersburg plan. Soon after the reorganization of the Bureau into Institutes, plans were developed for placing the study of architectural acoustics in the Institute for Applied Technology, while the more basic work on sound propagation and measurement would be located in the Institute for Basic Standards. New facilities for architectural acoustics were included in the early plans for the Sound Laboratory at Gaithersburg. However, cost considerations and lack of emphasis on this program at the time caused the architectural acoustic facilities to be deleted in the construction plan. The need for climatic exposure facilities grew out of the inability to predict with sufficient certainty the performance of full-scale roofs, walls, floors, and other building elements exposed to natural conditions from the laboratory results of much smaller specimens subjected to a simulated environment.

Thus the loss of major furnace facilities for fire research and the loss of sound transmission chambers for architectural acoustics brought about by the relocation of the National Bureau of Standards, and the need for full-scale study of the effect of natural climatic conditions on building elements, gave these three facilities first priority in the long-range construction plans of the Building Research Division.

2. Activation of the Ad Hoc Task Group

A request for funds to prepare engineering and architectural plans for these three facilities was first forwarded to the Bureau of the Budget in the budget request for Fiscal 1968. Because several years had passed since the original plans for some of these laboratory structures had been formulated, and because of the changes in physical location of NBS and in the organizational structure of the Bureau, the Director of the Institute of Applied Technology established an ad hoc Task Group to study intensively the program and physical facilities requirements of NBS in the areas of fire research, architectural acoustics, and climatic exposure. In the spring of 1967 a bill was introduced into the 90th Congress that would establish a Fire Center in the National Bureau of Standards which would administer fire research programs, fire information retrieval, educational and training programs, and demonstration projects in behalf of the Secretary of Commerce. The possibility that this Congressional bill would be enacted was taken into account in the planning for fire research. The ad hoc Task Group was comprised of three private consultants with broad experience in fire research, architectural acoustics and structural design of laboratory facilities, respectively; senior staff personnel of NBS from the Structures, Fire Research, Environmental Engineering, and Building Systems Sections, and the Plant and Building Research Division offices; and a special assistant to the Institute of Applied Technology concerned with developing advisory information relative to the formation of a Fire Center. The composition of the Task Group is identified at the end of Chapter 1.

3. Objectives of Task Group Study

The ad hoc Task Group was given the following charge at its first meeting on May 23, 1967:

(a) to analyze and outline the national needs in the areas of climatic exposure, architectural acoustics, and fire research;

(b) to assess the available facilities and technical capabilities throughout the U. S. and selected foreign countries for research and technology in these disciplines;

(c) to identify the legitimate areas of Federal Government activity and the potential for utilizing other facilities;

(d) to describe, in a functional manner, the size, number, type, arrangement, and location of the buildings and facilities required to carry out the Federal program in terms of dimensional characteristics of laboratory facilities and enclosing structures, range of control of environmental conditions, kinds of investigations to be made, rate of flow of test specimens, utilities requirements, etc.;

(e) to explore and describe the potential for making common use of service and test facilities in the proposed new construction by more than one discipline;

(f) to recommend preferred locations at the Gaithersburg site of NBS, or elsewhere, for these facilities;

(g) to estimate cost of planning, construction, and operation of the programs and facilities, to the degree possible from a functional description of these requirements;

(h) to consider the organizational and functional relationship between the Building Research Division and the Fire Center, if the latter is created;

(i) to prepare and submit a report describing the research needs, Federal facilities requirements, type of staffing, estimated cost, and cost-benefits for each of the three areas of applied science.

The Task Group performed its work through subcommittees which were assigned to the major components of the problem, with interspersed meetings of the whole Task Group to review and coordinate the overall results. Additional technical personnel from NBS were assigned to the subcommittees to facilitate the collection, analysis, and presentation of data and information.

4. Task Group Composition

The membership of the Task Group was as follows:

Dr. R. A. Hechtman, Pres., R. A. Hechtman and Associates, McLean, Va.
Prof. H. W. Emmons, Division of Engineering and Applied Physics, Harvard University, Cambridge, Mass.
Mr. L. S. Goodfriend, Pres., Goodfriend-Ostergaard Associates, Cedar Knolls, N. J.
Mr. J. P. Eberhard, Director, Institute for Applied Technology, NBS.
Dr. J. R. Wright, Acting Chief, Building Research Division, NBS.
Mr. Hylton Graham, Chief, Plant Division, NBS.
Mr. J. F. Christian, Special Assistant to Director, Institute for Applied Technology, NBS.
Mr. R. W. Blake, Chief, Building Systems Section, NBS.
Dr. E. O. Pfrang, Chief, Structures Section, NBS.

Dr. A. F. Robertson, Chief, Fire Research Section, NBS.
Mr. H. E. Robinson, Chief, Environmental Engineering Section, NBS.
Mr. P. R. Achenbach, Deputy Chief, Building Research Division, NBS, Chairman of the Task Group.

In addition, the following members of the NBS staff served on subcommittees of the Task Group throughout the study:

Mr. P. T. Chen, Plant Division.
Mr. R. D. Berendt, Sound Section.
Mr. W. C. Cullen, Chief, Materials Durability and Analysis Section.
Mr. F. J. Powell, Assistant Chief, Environmental Engineering Section.

CHAPTER 2

Executive Summary of Program and Facilities Requirements

1. Background of the Recommendations

Analysis of the evolution of the building industry and its current organizational structure indicates that this industry is not highly motivated toward research to improve fire safety, noise control, and the resistance of buildings to climate-induced deterioration, for the following reasons:

1. The building industry in basically a craft industry, and is comprised of a very large number of small, medium, and large business enterprises.
2. A very wide variety of natural and manufactured materials is used in buildings.
3. Many of the physical features of buildings are regulated by municipal building codes.
4. Fire safety, acoustics, and durability are owner-oriented properties of buildings without strong demonstrable sales appeal.
5. The fire safety and acoustical properties of a building are essentially systems problems of great complexity.
6. The deterioration of buildings is a long-term process involving chemical and physical phenomena that are not well understood and for which the builder and designer currently assume only short-term responsibility.
7. There are significant areas of incompatibility among the important properties of materials that provide desirable fire safety, acoustic, and durability characteristics.
8. The building industry has no centralized research facility or organization.

2. Climatic Exposure Requirements

The climatic exposure investigations require a single building. The response of the fabric and components of this building to the interacting forces of the weather subsystem, the foundation subsystem, and the service-imposed environmental subsystem would be the subject of study. Approximately a dozen different investigations would be carried out simultaneously on structural movement and deterioration; distortion, deterioration, and changes in properties of materials; and the effect of building deterioration on the environmental characteristics of heat, air and moisture transfer, and acoustics. The principal objective of this research is to obtain the knowledge required for reducing the annual average expenditure of $11.5 billion in this country for maintenance, repair, and improvement of buildings, caused principally by climatic effects. The first cost of this structure is estimated at $1,030,000 for design, construction, and equipment. The annual operating cost is estimated to be $240,000.

3. Architectural Acoustics Requirements

The national deficit of technical information in architectural acoustics is comprised of several important parts; namely, methods of testing and rating absorptive materials, sound-isolating walls and floors, and assemblies of building elements; coordination of U.S. test methods with international standardization; investigation of structure-borne sound and vibration in buildings; methods for inter-comparing acoustic measurements in different laboratories of the country; correlation of laboratory measurements with field performance; studies of noise problems of mechanical systems; integration of systems for air-conditioning, light and sound control; and the relationship between room background noise and occupant satisfaction. There has been no focus of leadership in the United States for test development and standardization in architectural acoustics, largely because the solution to acoustic problems almost always involves division of responsibilities among designer, manufacturer, builder, artisan, and client. The laboratory facilities for carrying out the needed research and technology in architectural acoustics can all be accommodated in a single large building, and could make use of common specimen preparation and storage areas with other disciplines. Such a building should include a reverberation chamber, anechoic room several side-by-side and two-story transmission chambers, a psychoacoustics laboratory, a scale-model laboratory, a sound and vibration measurements laboratory, a simulated field-test structure, and suitable control rooms for these special laboratories. An instrumented van for making field measurements of noise, reverberation, and sound transmission is also required.

The only two rooms in the proposed Architectural Acoustic facilities and the Sound Laboratory facilities now being completed at Gaithersburg that are comparable are the reverberation and anechoic rooms. However, these two rooms in the Sound Laboratory will be fully occupied in more fundamental work on properties of materials, investigation of sound fields, calibration of transducers, and the development of measurement and calibration techniques, and will not be available for architectural acoustics.

The total estimated costs for design, construction, and equipment for this facility are $6.15 million, and the annual operating cost is estimated at $750,000.

4. Fire Research and Safety Requirements

A comprehensive fire research program is described that will bring modern science and technology to bear on all aspects of the fire prevention problem and provide a basis for reduction in the annual loss of 12,000 lives and $1.7 billion in property. The program is divided into two parts: fire research and engineering, and fire safety and information.

The first part deals with technical investigations to delineate the various aspects of the fire hazard problem including ignition, fire spread, toxic products, flammability of materials, fire performance of building systems, fire detection and suppression, the behavior of people in fires, operating techniques for fire-fighting organizations, and medical research related to burns and asphyxiation. This program would entail an annual operating cost of about $22.7 million, half of which would be performed in new facilities at the National Bureau of Standards and require a staff of 400. Seven buildings are indicated in this report for this part of the program, including an experimental fire research building, a building for offices and general purpose laboratories, a structural fire test building, a building for specimen preparation and storage, a structural fire test floor, a high-rise fire test building, and a data recording and handling structure. However, actual design of this complex may reveal that several of these proposed structures can be economically combined. Most of these facilities can be accommodated on the present Gaithersburg site by incorporating suitable smoke abatement equipment. However, it is recommended that a remote site of about 30 acres be obtained for the high-rise fire test building, the test area for burning full-scale buildings, and the structural fire test floor, because the smoke production of these intermittent studies will exceed the capacity of any practical smoke-abatement system.

The second part of the program provides for the collection and analysis of fire statistics, analysis of the fire hazard involved in domestic and industrial operations, educational programs to make this information and understanding available to firemen and to the public, demonstration programs for new techniques, and a library and fire science information center. This program would be largely done by contract to organizations outside of the National Bureau of Standards, with only about 5 per cent of the total funding of $34.7 million being used in-house for monitoring the program.

The initail cost for the facilities required for this program is estimated at $1.44 million for design and $26.5 million for construction and for the major equipment required.

CHAPTER 3

Full-Scale Research Facility for the Study of the Effects of Climatic Exposure on Buildings

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Chapter 3

Full-Scale Research Facility for the Study of the Effects of Climatic Exposure on Buildings

1 Summary

The annual value of all types of new construction in the United States amounts to 10 per cent of the Gross National Product. Fifteen per cent of this total, or 1.5 per cent of the GNP, is spent each year simply on the maintenance, repair, and improvement of buildings. The major forms of deterioration caused by climate-related phenomena include the damage from movements of the structural frame resulting from diurnal and seasonal changes in temperature and humidity; from expansion, contraction, and settlement of foundations; from the effects of wind, sun, rain, hail, and temperature on roofs and walls and sealing materials; from entry of moisture into walls, roofs, and joints; from moisture penetration into on-grade floors from the earth; from corrosion and other kinds of chemical changes; from shrinkage due to drying; and from discoloration due to solar irradiation. The objective of the program described herein is to investigate these kinds of deterioration in order to provide more accurate and meaningful information and data leading to better methods and quality of construction and to improved, more durable building materials, with the purpose of substantially reducing the costs of maintenance and repair.

This section develops the concept of an adequate, but minimum, research program on the deteriorating effects on all important aspects of the performance of the building, of weather, the foundation interface, the service-imposed interior environment and building-use, and the progressive loss of resistance of the building components and materials. The objectives of this research are to define more clearly what these damaging effects are, improve methods of measuring and observing them, and ascertain what correlation exists between a full-scale climatic test of a building system and present small-scale sample tests. To accomplish these objectives, the construction of a full-scale building is proposed, the fabric of which would itself be the subject of investigations. It would be specially built to incorporate many common forms of construction and materials. The building would be subjected to a natural climatic environment and normal interior service conditions. Projects are described which have been designed to utilize this facility effectively to obtain the needed data and information.

2 National Need for Research on Climate-Related Deterioration of Buildings

2.1 Annual Cost of Building Maintenance

The annual value of all new construction in the United States amounts to about $75 billion or approximately 10 per cent of the Gross National Product. In addition, some $11.5 billion are expended annually on maintenance, repair, and improvement of buildings alone. The major portion of this expenditure results from causes related to climatic conditions and changes. A substantial portion of the benefit of this large expenditure is lost because of lack of adequate engineering information about the performance and breakdown of building systems under the deteriorating effects of climatic exposure.

A summary of the major types of deterioration and damage resulting from climate-related causes and the estimated amount of dollar loss follows:

Damage caused by penetration of moisture through walls, roofs, and joints	$2 Billion per year
Replacement of roofing and insulation	$500 Million per year
Loss of heating and cooling because of wetted insulation in roof	$100 Million per year
Replacement of flooring damaged by moisture penetrating on-grade floors	$500,000 per year
Settlement of foundations and other permanent movements of the building structure	Amount large, but unknown
Deterioration of the materials in the building	Amount large, but unknown

In many cases, (1) building costs are increased by overdesign in the attempt to minimize climate-caused deterioration and (2) losses occur because of the lack of a sufficient knowledge of how to design climate-resistant buildings.

2.2 Need for Research

Only a very small percentage of the gross income of the construction industry is invested in research and development, and most of this investment is in product development. Despite the large volume of construction required of this major industry, its profit margins are quite small, and, therefore, its research expenditures are very small proportionately to most other industries, particularly those with the larger R&D programs such as electronics and pharmaceuticals.

Further, construction materials manufacturers ordinarily market a narrow line of products which constitute only a few of the many components found in a building. For this reason, they have little interest in testing even a small subsystem of building components unless their product is used in combination with the product of another manufacturer, but tend to test single samples and small-scale specimens almost exclusively. Costs, time requirements, and proprietary constraints are likely to prevent or deter a single manufacturer or trade association from investigating the performance of subsystems as a part of a full-scale building.

Finally, it is often not possible by means of small-scale laboratory measurements to determine adequately and correctly the service performance of subsystems in buildings which in actual construction are full-scale, highly interrelated, and subject to a variable and rapidly changing outdoor environment.

Accordingly, a national need exists for an effective research program on the effects of climate-related exposure upon the performance of a building system which is made up of various kinds of construction and selected combinations of materials.

3 Program of Research

3.1 Environmental System to Which the Building is Exposed

The total environmental system to which the building is exposed might be broken down into the following subsystems:

- Weather Subsystem:
  - Air temperature
  - Humidity
  - Dewpoint
  - Wind pressure
  - Precipitation
  - Insolation
  - Contaminants
- Foundation Interface Subsystem:
  - Foundation material
  - Prepared subgrade
  - Groundwater and drainage
  - Ground temperature
- Service-Imposed Environmental Subsystem:
  - Interior temperature
  - Interior humidity
  - Ventilation
  - Structural loadings
  - Movements and differential movements of components of building caused by structural loadings
  - Wear caused by use
  - Noise and vibration
- Subsystem of Primary Effects with Feedback Effects into the Building System:
  - Dimensional changes in building components
    - Expansion and contraction
    - Permanent changes - shrinkage, creep, expansion, displacement

Settlement and other movements of foundation
- Changes in properties, resistance, and durability of building components and materials
- Changes in moisture content of materials
- Failure, cracking, and fracture
- Other forms of deterioration of building components and materials, often due to the action of unwanted water.

3.2 Interrelation and Interdependence of Building Subsystems

The reaction of the building to its climatic environment is that of a system, and not of a series of isolated and unrelated effects. For example, the movements of the structural frame resulting from the diurnal and seasonal temperature changes and variations in humidity; the expansion, contraction, and settlement of the foundation; and the shrinkage, expansion, and contraction of the materials of the structure are not only interrelated among themselves, but produce a number of other problems such as cracking of exterior and interior wall finishes, cracking of walls and partitions, failure of vapor barriers and caulking, which lead to the penetration of moisture into the building and the insulation. The interrelation and interdependence of the various principal components of the building, while functioning as elements of the different subsystems of the building, have been noted in Table 3.1. The column at the left of this Table lists principal components of the building system. The functional subsystems are listed in the other column headings. In this matrix, the combinations of building components serving as elements of each functional subsystem are checked. It can be seen that most of the building components (1) serve as parts of several subsystems and (2) are required to perform a number of apparently unrelated functions.

The logic of testing a building system as a whole, subjected to its normal service environment, becomes apparent from the analysis of Table 3.1. Tests of small samples of building materials or of a single building component serve a useful purpose in making a preliminary exploration of deterioration under climatic exposure, but fail to include the important and significant effects transmitted through the related actions of other components of the building system. Moreover, as is shown by Table 3.1, when a building component actually serves a number of functions under normal operating conditions, as for example, a roof deck to structural support, the heating and air conditioning system, resistance to the penetration of moisture, and an acoustical dampener; tests of small samples do not duplicate simultaneous in-service conditions.

TABLE 3.1

FUNCTIONAL INTERRELATION AND INTERDEPENDENCE OF BUILDING SUBSYSTEMS

Principal Component of Building System	Subsystem Identification						
	Structural	Exterior Wall	Roof	On-grade Flooring	Htg.,Vent. & Air-Cond.	Fire Behavior	Acoustics
Foundation	x	x		x			x
Prepared subgrade	x			x	x		x
Footings	x	x					x
Columns	x	x			x	x	x
Beams	x	x			x	x	x
Beam-Column Connections	x	x			x	x	x
Subfloor on grade	x			x	x	x	
Intermediate Floors	x				x	x	x
Floor-frame Connections	x					x	x
Exterior Walls	x	x			x	x	x
Wall-frame Connections	x	x			x	x	x
Roof deck	x	x	x		x	x	x
Roof deck-frame Connections	x		x		x	x	x
Joints, Caulking, Sealants	x	x	x	x	x	x	x
Partitions (interior)	x				x	x	x
Vapor Barrier -- roof	x		x		x	x	x
Vapor Barrier -- on grade	x			x	x	x	x
Vapor Barrier -- exterior wall	x	x			x	x	x
Roofing			x		x	x	x
Insulation	x	x	x	x	x	x	x
Exterior Wall -- exterior finish	x	x			x	x	
Exterior Wall -- interior finish		x			x	x	x
Floor covering and adhesive				x		x	x
Heating and Distribution					x	x	x
Cooling					x	x	x
Ventilation					x	x	x

3.3 Effects of the Environment on the Building System

Such tests would require regular measurements to indicate the behavior and changes in behavior with time, of the building system and its components. Typical kinds of experimental observations could include the following:

For structural components:
- Changes of stress in members
- Permanent dimensional changes in members: creep, shrinkage, differential movement in connections and joints
- Expansion and contraction
- Failure, cracking, or fracture of members, connections, and joints

For materials:
- Permanent dimensional changes - shrinkage, expansion, creep
- Expansion and contraction due to temperature and moisture changes
- Failure, cracking, or fracture
- Changes in properties, resistance, and durability of materials
- Corrosion and deterioration
- Moisture content and transfer through material
- Air infiltration through materials and joints
- Noise absorption and transmission.

For interior environment:
- Air temperature
- Humidity
- Ventilation and movement of air
- Moisture and vapor transfer through walls, roof, floors, on-grade floor, and joints.
- Heat transfer through walls, roof, floors, on-grade floor, and joints
- Air infiltration through walls, roof, floors, joints, seals, caulking, and openings
- Moisture content of materials
- Arrangement and subdivision of interior space and openings between spaces
- Acoustical environment.

Such typical measurements would be evaluated to determine the performance of the building relative to its various subsystems and the best criteria for judging performance. There could also be ascertained, in many cases, the degree of correlation between the performance of building subsystems as a part of a full-scale building and the performance of small-scale tests of small specimens.

3.4 Objectives for Program of Research

The principal objective of this program is to study the long-term performance of a full-scale building under natural climatic exposure as a means for developing improved technical data and design requirements for buildings that will lead to reduced deterioration and greater economy in operation and maintenance. This full-scale building would include many forms of construction, such as some six or eight combinations of roofing, insulation, vapor barrier, and type of roof deck; various kinds of on-grade floor construction; different types of exterior walls; and the use of different materials to serve the same purpose.

Climatic exposure experiments would include the time-dependent behavior of a reinforced concrete structural frame and foundation system; performance of various designs of roofing; self-drying of insulated roof constructions; the effects of sub-floor moisture conditions on flooring and adhesives laid on on-grade floors; the weather resistance of exterior walls; the heating-cooling loads of a building; the variation of the moisture content of the building materials as related to their fire resistance; weather engineering; in-situ methods of measurements; and the use of an inflatable balloon during construction as a weather shield. Other experiments include acoustics, instrumentation, and data-handling. The details of these projects are presented in Section 6.1 of this report.

There is a long history of use of climatic exposure tests to develop data on durability or performance of building exterior materials. These have been achieved by exposure to natural climatic conditions of samples of materials, wallettes, panels or cubicles of various kinds. Heating load measurements have been made for both unoccupied and occupied houses of various types. The aim and impact of the proposed facility is not to replace any or all of such useful measurements, but to extend present performance of the subsystems of a building in full scale, and to develop improved weather-response data, and methods of analysis and criteria of performance in-situ and under the transient temperature conditions resulting from climatic changes.

4 Implementation of Program of Research

4.1 Conditions for Effective Implementation of Program

A program of research for the investigation of the deteriorating effects of climatic exposure and related service-imposed conditions upon building systems and the objectives of this program have been outlined. Consideration of the conditions necessary to accomplish successfully the objectives of providing meaningful data and test results indicated clearly that the preparation of the test facility, the selection of the experimental observations, instrumentation, and the method of evaluation of the data must be planned and designed with the purpose of maintaining control and understanding of the experiment throughout its course. It was apparent that at least six conditions were necessary to realize the objectives of the program: (1) firm control over the design, specification and testing of the materials for the facility, and construction; (2) a full-scale experimental building; (3) a building exposed to typical natural weather condtions and not to artificially produced or accelerated weathering; (4) experiments to be performed simultaneously so as to be related; (5) experiments to be carried out in real time and not under accelerated conditions; and finally (6) tests to be made under a total actual field environment, so as to evaluate properly in-situ performance.

These criteria are used in Part A and operational requirements in Part B of Table 3.2, as column headings. The first column lists the subject areas of experiments to be performed, which will be described in detail in Section 6.1.

4.2 Means for Accomplishing the Objectives of the Program

Six different methods or options for accomplishing the objectives of the research program were analyzed in depth by evaluating the degree to which each option would attain these objectives. A typical analysis is shown in the matrix of Table 3.2, for Option I in the following list:

I. Laboratory tests using simulated conditions as much as is practical;

II. Use of existing government buildings or new government buildings;

III. Use of non-government buildings;

IV. Case-study approach that involves no direct experimentation or measurement; but investigates past studies and field failures;

V. Stimulation of others to do this research;

VI. Construction of a full-scale NBS facility to conduct experiments necessary to accomplish the objective.

The typical evaluation in Table 3.2 was made for each of the six options for the purpose of determining how well it attained the objectives of experimental subjects.

TABLE 3.2

SAMPLE EVALUATION OF OPTIONAL METHODS OF STUDY

OPTION 1. Laboratory Tests Using Simulated Conditions

Subject Areas of Experiments	Part A: Experimental Requirements as Met by This Option						Part B: Operational Requirements		
	Firm Control	Full Scale	Natural Weather	Simultaneous Experiments	Real Time	Field Conditions	Technical Feasibility	Economic Feasibility	Manage-ability
Structural	4	3	0	0	0	0	3	2	2
Roofing	4	1	0	0	0	0	3	2	3
Self-Drying Roofs	4	0	0	0	0	0	3	2	3
Flooring	4	3	0	3	2	3	4	3	3
Heating and Cooling Loads	4	3	3	4	0	1	4	3	3
Walls	4	3	0	1	0	1	3	3	3
Moisture Content (fire safety)	4	3	0	1	0	1	3	3	3
Acoustics	4	1	0	3	0	1	3	3	3
Weather	1	1	1	1	0	0	2	2	2
Instrumentation	4	4	2	4	4	4	4	4	4
Balloon Construction	4	0	0	1	0	0	1	1	1
Data-Handling Methodology	4	4	4	4	4	4	4	4	4
In-situ Methods	2	1	2	4	3	2	3	3	3

Rating Scale: Rating of 0 = Requirements not met (No)
Rating of 4 = Requirements fully met (Yes)

4.3 Analysis of Options for Implementing the Program

The analysis of six options listed in Section 4.2 examined different means of carrying out the program. The method of analysis used in Table 3.2 was as follows:

1. A scale of achievement of the requirements in Parts A and B with a range of five levels between "no" and "yes" was set up. Each of the three committee members applied his own estimate of the potential achievement of the requirements to develop a matrix such as is shown in this Table for one member's opinions.

2. The average of all the estimates was computed separately for Parts A and B for each member's opinions.

3. The square root of the product of the two average values from Step 2 was found as the evaluation of the Option by one committee member.

4. The values for the separate committee members from Step 3 were combined by taking the cube root of their product; this number was considered to represent the evaluation of the Option.

The numerical evaluations of the six Options thus determined were as follows:

Option I: Laboratory tests	2.03
Option II: Use of existing government buildings	2.52
Option III: Use of non-government buildings	2.45
Option IV: Case-study approach	1.90
Option V: Stimulation of others to do this research	2.18
Option VI: Construction of full-scale NBS facility	3.87

Option VI was found to be most desirable. No better way was known to obtain the information sought than in a climatically exposed building designed to incorporate full-scale experiments with necessary special instrumentation and control of construction. The data obtained should be directly applicable to other buildings, without need to adjust for the difference between laboratory tests and in-situ service. Further, a unique opportunity would be provided to analyze statistically and in-depth the data obtained over a five year period.

The other options were not acceptable because of major deficiencies. For example, Option I would not satisfactorily duplicate in-situ conditions of weather and moisture content, interaction of experiments, and scale. Options II and III would not provide control of building design and construction, would be difficult to manage, and would be expensive to implement and operate. Option IV would not allow sufficient coordination of data and probably would not involve sufficient experimental data at all. Option V, involving promotional operations, would be expensive and lack overall control of the investigation.

Implementation of Option VI would enable the development of information on in-situ performance of buildings and their elements.

5 Proposed Research Facility

5.1 General Nature of the Proposed Facility

This program would plan, design, and erect a full-scale climatic-exposure building facility, special in that several of its parts or subsystems are themselves to be the prime subject of building research investigations involving their performance under natural climatic exposure conditions not totally duplicable in laboratory testing. Highly interrelated engineering investigations are to be performed covering a period of about 5 years, involving weather, roofings, insulated roof constructions, walls and partitions, flooring, building moisture content, air conditioning loads and systems, and acoustic measurements. A two-story building, about 50 x 100 feet in plan, could well serve the purpose of this project.

A relatively new construction technique is also proposed that involves winter-time erection of the building beneath a continuously air-pressurized plastic hemispherically shaped balloon with measurement of the environment between the balloon and building under construction and collection and analysis of scheduling times and costs. This technique would greatly assist in reducing the moisture entrapped in the building during construction. Balloon shelter during construction, if feasible, could also have very important economic value by enabling construction programs to proceed during inclement or winter weather.

To achieve economy and avoid redundancy in recording data and evaluating results, a central automatic instrumentation system capable of input into an NBS computer facility is proposed instead of data acquisition and reduction by each of the twelve investigations separately. With the data acquisition system proposed, there will be opportunity of a pioneering kind to develop statistically-meaningful data on conditions to which buildings and materials are subjected in use, and on their response. In all investigations, the opportunity to acquire well-characterized long-term performance data on the building fabric and interior environment in response to actual outdoor weather exposures is of major importance and of much technical interest to the government, industry and professional architects and engineers.

5.2 Specific Requirements for the Facility

Summarized below are the more important specific requirements for the climatic exposure research facility:

a. Geographic Location - On the site of the National Bureau of Standards at Gaithersburg, Maryland. Of the possible geographic locations within this country, the Gaithersburg area offers a good compromise with respect to the upper and lower extremes of temperature, frost, and insolation.

b. Building Orientation - Building front, one of the short sides, facing due East with enough clear area around the building to prevent distortion of prevailing winds and to prevent sun shadows from adjacent buildings.

c. Building Shape and Size - Preferably rectangular with width dimension a minimum of 50 feet and height sufficient for two stories. Length optional to satisfy experiments - 100 feet suggested.

d. Footings and Foundations - Some pre-cast and some cast-in-place concrete.

e. Columns and Spandrels - Reinforced pre-cast concrete spaced 20 feet on centers with a multiplicity of types of connections.

f. Roof Beams - Reinforced, pre-cast, pre-stressed, concrete, 50 feet long (width of building), spaced 20 feet on centers.

g. Basement and Floors - There will be no basement. The first floor will be of slab-on-grade construction. The heating and air-conditioning equipment will be located inside the structure on the ground floor level. The floor between stories may be of several constructions to accommodate acoustic and other experiments.

h. Walls - The longest walls will be pre-fabricated, some of 20 feet wide units, and shall contain windows. Units should be designed to enable removal from the structural frame. Cross-sections of these walls will vary with experimental requirements. The east wall should be windowless and its exterior made of brick to harmonize with other buildings at NBS. The west wall will consist of a segmented arrangement of several windowless types of wall, each of a minimum of about 100 square feet in area.

i. Roof - The roof will consist of several types of construction and should be a minimum of 50 feet wide to accommodate that length of run of built-up roofing systems. The proposed self-drying insulated roof constructions require a minimum area of 100 square feet each.

j. Heating, Ventilating, Air Conditioning and Mechanical Systems - The type of heating, ventilating, and air conditioning systems and precise conditions for controlled indoor temperature and relative humidity will be selected after the building dimensions are firm.

k. Utilities - Electric power, plumbing, lighting and other services suitable for the laboratory studies will be installed initially. Depending upon cost and other factors, later conversion of the building to other purposes, or alternately demolition after 5 to 7 years work, should be taken into account in the initial design of the utilities systems.

l. Access During Construction - It is imperative that the construction of all elements of the building be precisely in accordance with specifications and that scientists and engineers have free access to all parts of the building during the construction phase in order to install transducers into the building fabric as it is erected. This need would be facilitated by NBS serving as its own contracting agency for this building.

m. The designer and construction contractor should keep in mind the use of an inflatable structure as a weather-shield during winter-time construction.

n. Innovations should be encouraged.

5.3 Operational Requirements for the Experimental Program

Each of the engineering experiments impose operational requirements for successful conduct of this project. Those presently known are listed below for possible use in the design phase of this enterprise.

a. The indoor temperature and relative humidity of the building will be controlled within selected limits during the entire service life of the experiments.

b. Except as occupancy may become a condition of the experiment, only authorized research personnel engaged in the tests should have access to the building or use it. The reconstruction of damaged building components, installation of new components, moving or replacement of partitions, the wide range of interior temperatures and humidities used during tests, and the protection of instrumentation would render ordinary occupancy undesirable during the tests. After the experimental use of the building has terminated it might be possible to use the building for other purposes.

c. Space allocation for operational needs consists only of an instrument room and selected areas of floors for flooring experiments. Therefore, considerable architectural and engineering ingenuity concerning room and facilities layout can and should be done.

d. Convenient access to instrument and transducer circuits should be provided.

e. Service contracts on instrumentation and transducers used are mandatory including the provision that service personnel reside locally.

f. Warning and indicating systems in the event of power or services outages are required.

6 Proposed Projects Under Research Program

6.1 Description of Proposed Projects

Major projects were identified as follows: time- and load-dependent structural behavior of precast, prestressed concrete building frame and foundation systems; weathering, differential movement and deterioration of built-up flat roofings; self-drying and thermal insulating characteristics of flat insulated roof constructions; moisture effects on the durability of flooring systems; the engineering behavior of wall systems including heat and moisture transfer, joint effects, movements, and leakage; heating and air conditioning system performance and loads; acoustical performance of the building and its elements; time-dependent moisture content of major elements of the building from a fire resistance viewpoint; detailed record of incident weather and of the thermal response of the building; and in=situ methods of measurement including instrumentation and demonstration of the use of inflated plastic balloon-type covering as a construction technique for foul weather and also to measure and control the environment between the balloon and the building under construction.

More detailed descriptions of projects to investigate the above subjects follow.

6.1.1 Structural Engineering Experiments

The objectives of the structural engineering experiments are to investigate the time-dependent structural behavior in-situ of a precast, prestressed, steel-reinforced structural frame and foundation system that contains several types of joints and connections and to study the correlation of weather with phenomena involving cracking, creep, deflections, building settlement, loss of prestress, etc. The behavior of interfaces of foundation to floor and wall, walls to floors, walls to roof, including possible correlation with out-door weather, is of particular interest.

Many of the designs for structural engineering systems are based on theoretical considerations verified by laboratory tests. Design problems that cannot be readily handled theoretically are usually solved by empirical means. A large body of experience is available but little information is available concerning the actual in-situ performance of structural systems that in practice are dynamic. There is a need to compare performance as predicted at the time of design with the actual performance. Such comparisons become especially important with the trend toward industrialization of building construction and larger scale prefabrication of major building elements.

Masonry is one of the most widely used types of building construction for both residential and industrial buildings. Much has been done to control its cracking in the design stage but improvement is still needed. The development of design criteria based on in-situ performance for better control of cracking in masonry is urgent. In-situ observation of the drying shrinkage of masonry units that cause length changes and unsightly cracking is needed under conditions of full-scale, three-dimensional, climatic building exposure.

The design of the structural experiments consists of two types of foundation and footing construction. (See Figure 1) The first is of conventional monolithic concrete and/or concrete block placed on the site; the second is a prefabricated foundation system that is joined only on site. The footings will support a number of precast columns of two-story height. Precast beams will be used to join columns at mid-height and top. The roof beams are to be prestressed and of a span of 50 feet. A spacing of 20 feet between main structural columns and roof beams is suggested. No special structural requirements are needed for wall cladding, floors, or roofing, except that the joining techniques should be such that different types of joints, connections, and movements can be studied. If practicable, claddings should be capable of being individually removed at will. Comparison of selected areas designed to show masonry cracking and those designed to prevent cracking are desired. Measurements of the settlement of the structure, loss of prestress in roof beams, creep, deflections, and performance of joints and connections, are planned.

The quantities to be measured include expansion and contraction movements, deflection movements, loads on roof, walls, columns, foundations and footings, wind forces and pressures on the exterior faces of the building, temperature, relative humidity of air spaces, moisture content of materials and a complete outdoor weather history. The methods of measurement for these quantities are developed and available. Suitable transducers are available by purchase and will not need to be developed in the laboratory. A final count of transducers by type and number must await preparation of design drawings.

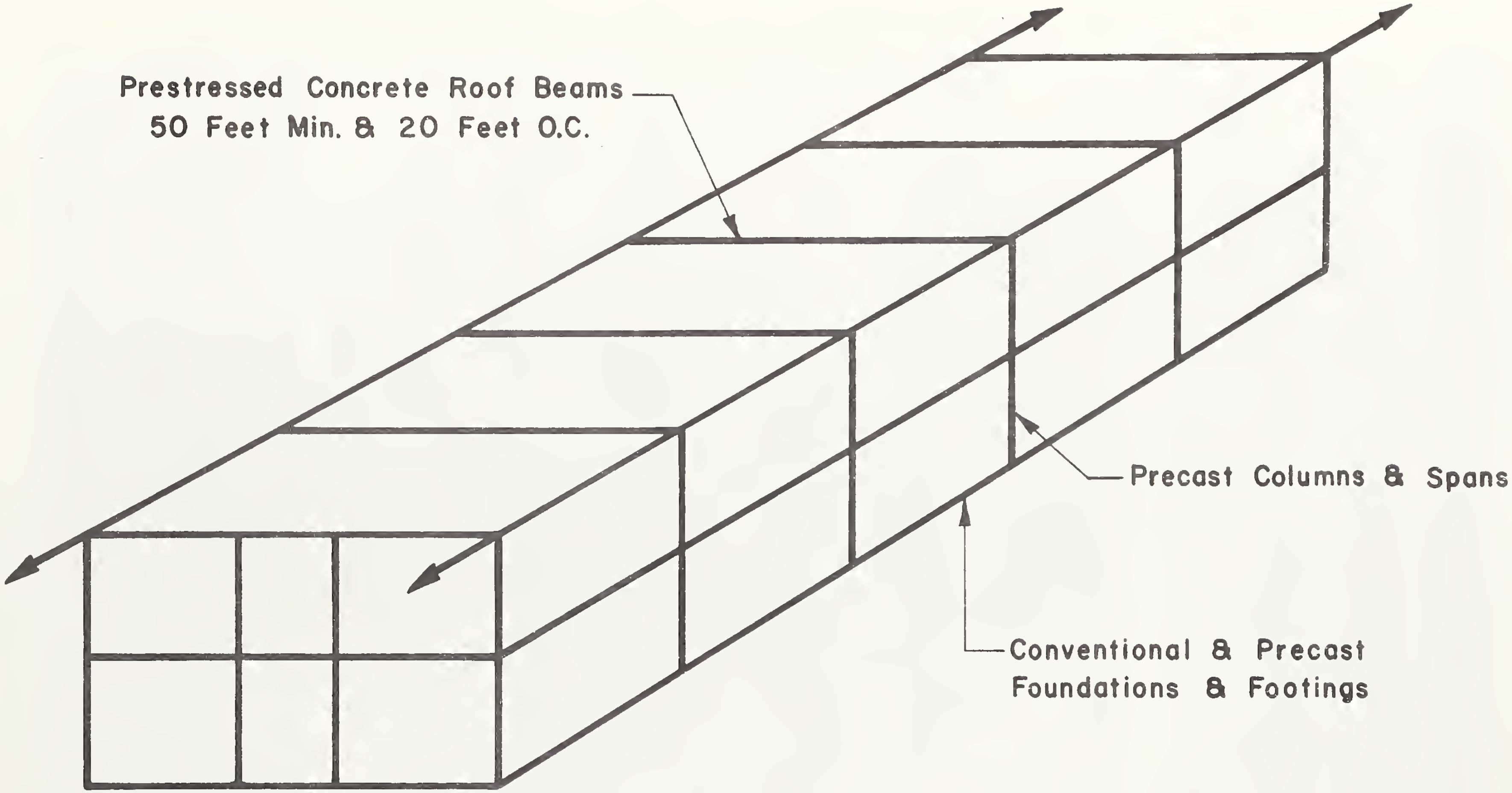

Fig. I. STRUCTURAL FRAME, FOUNDATION, AND FOOTING SYSTEM

Data reduction can be handled by computer although supplementary visual and photographic data will be needed for complete analysis. Close supervision of the fabrication of the structural elements will be required and considerable laboratory testing of materials used in construction may be necessary to determine physical properties of the materials used.

6.1.2 Roofing Engineering Experiments

The objectives of the roofing engineering experiments are to investigate the durability, deterioration and movement behavior of roofing materials by exposing several full-scale designs and arrangements of built-up roofings and roof coverings to natural weather. Also included is a study of the interaction and interdependence between components of a flat roof system and to relate available laboratory data to performance in service.

In the past, many of the important properties of materials have been determined adequately in the laboratory. Reports from the field or from actual observations of structures in service were used to relate laboratory data to field performance. Experience has shown that this is a costly and frequently unreliable means to obtain accurate data and an accurate history of actual field performance of roofing. The performance of the roof system cannot be properly predicted or evaluated solely on the basis of the chemical and physical properties of the individual materials comprising the components of the total system. The interdependence and interaction between and among all materials and components must be taken into account. The roof system may be defined as the covering on the top of the structure including the roofing, insulation, vapor barrier and roof deck. These components function as follows: roofing, the weatherproof covering; insulation, the thermal control element; vapor barrier, the moisture control element; and the roof deck, the structural platform. Premature failures of built-up roof systems, of which about 20 million squares ($100\ ft^2=1$ square) were applied in 1966, have been of great concern to architects, engineers, roofing manufacturers and contractors, and the owners. Field experience has shown movement to be a primary cause of the costly roof failures which have plagued the industry. In this area much fundamental information is needed to understand the cause and effect of the movements. In some cases, structural movements in the deck are suspected causes of failure while in others the movement between or within the thermal control element or movements of the membrane itself are listed as contributing factors in many serious failures. Thermal, moisture, or structural (creep) factors can cause movement in each or all components. The problem becomes extremely complex because of the many varieties of materials available and the almost infinite number of combinations possible. The performance data obtained and design criteria developed would serve as a useful guide in the selection of methods and materials in the design and construction of roof systems which will give continued and satisfactory performance under given exposure conditions.

The design of the roofing engineering experiments consists of five primary areas of the flat roof of the full-scale climatic exposure building facility. The minimum length of run of built-up roofing is 50 feet. Expansion joints will be used to separate areas. The performance of joints and all areas of flashing will be studied. (See Figure 2)

The quantities to be measured in all areas include temperature, linear displacement, stress-strain, pressure, moisture content, and a complete weather history with an indication of whether the outdoor roofing surface is wet or dry. The methods of measurement for these quantities are developed and available. A determination of the type and number of transducers must await preparation of design drawings. Data reduction can be handled by computer but supplementary photo-elastic analysis and considerable sampling of materials for laboratory tests will be required.

6.1.3 Self-Drying Roof Experiments

The objectives of the self-drying roof experiments are to obtain in-situ performance data of the heat transfer, moisture content, and self-drying properties of several full-scale designs of insulated flat roof constructions and of other types of constructions known not to be self-drying, if wetted. The in-situ performance data will be compared with laboratory data previously obtained under simulated temperature conditions on 2-foot square specimens, to demonstrate the feasibility or non-applicability of proposed performance requirements and criteria.

Buildings with flat roof constructions are very common in Government and private use. Roofing applied to flat roofs in 1966 in the USA aggregated about 2.0 billion square feet. A large, and probably increasing, fraction of the roofs incorporated thermal insulation to improve comfort within and to foster economy in indoor temperature control. Typically, insulated roof constructions perform these functions well as long as the insulation is substantially dry. Also typically, the construction fails seriously to perform them when the insulation is damp or wetted by water, a condition that can occur as a result of wetting during construction, or of rain penetration through accidental leaks in a new roof, or through leaks that occur as roofing deteriorates.

Conventional designs of insulated flat roofs usually have a vapor barrier membrane under the insulation to prevent entry

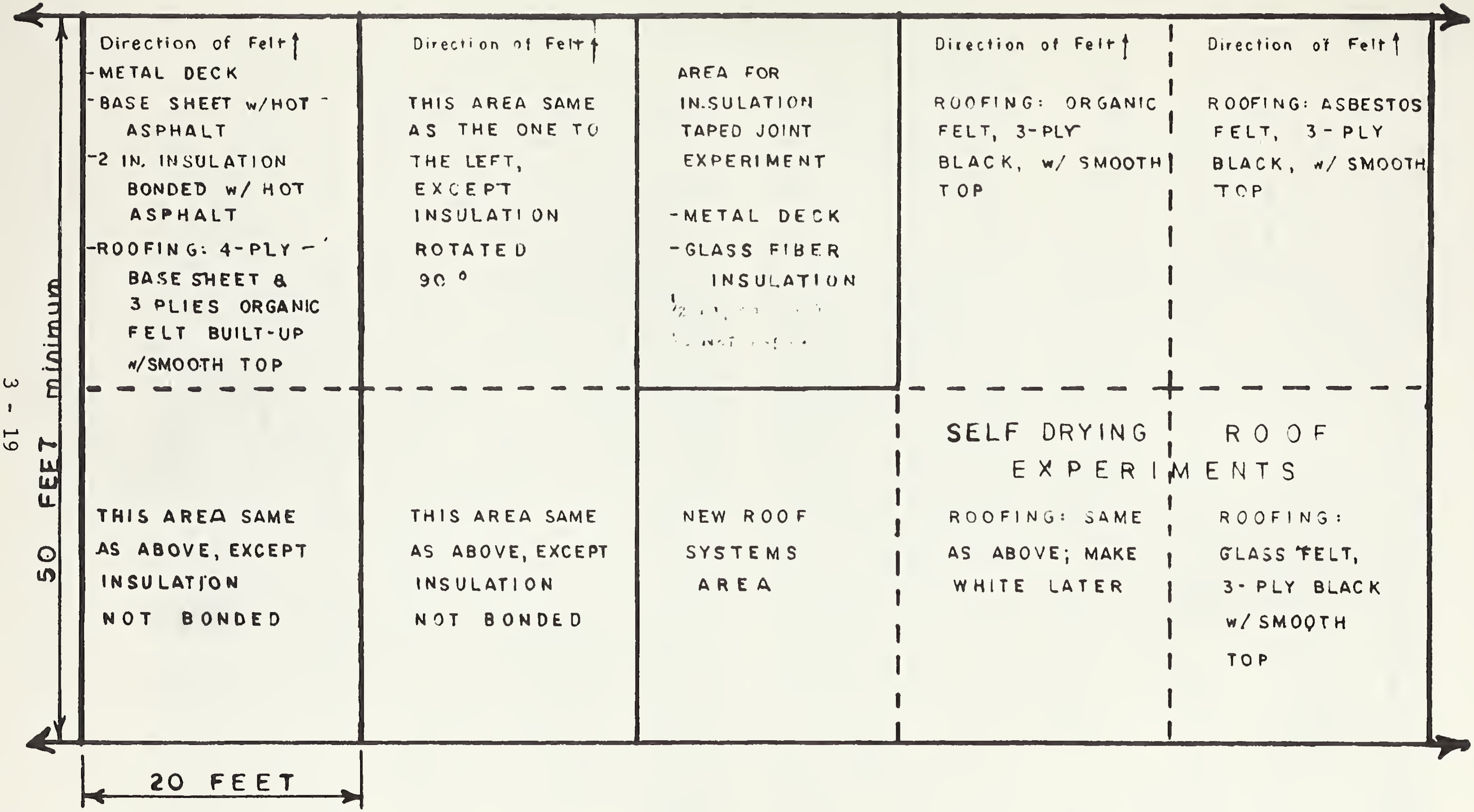

Figure 2. ROOFING SYSTEMS

of water vapor from within the building. In practice, however, wetted insulation confined between the roofing and vapor barrier cannot dry, and restoration of insulating value requires replacement of both insulation and roofing, at a minimal cost of $30 per 100 square feet. Experimental laboratory work conducted on small specimens at the NBS has shown that some insulated roof constructions which do not incorporate a vapor barrier, but instead employ a suitably balanced compromise between vapor permeance and water absorbing capacity, exhibit a substantial ability to dry out, if wetted, by expelling vapor downward when heated by the sun in moderate or warm weather, and thus rapidly recover insulating effect. Thus, a self-drying roof construction offers great promise as a practical solution to the problem of insulated roofs wetted by rain leaks. Its economic value is manifestly great.

Since it is unconventional (the deliberate omission of a vapor barrier under the insulation runs counter to customary ideas) it is understandable that evidence of the merit of self-drying constructions, to be most convincing to practical builders, must be based on tests of full-scale, or adequately large, installations exposed to actual weather conditions on an actual building. Present data are based on tests of 2-ft. square specimens subjected to laboratory-simulated exposure conditions. There is therefore, a very practical need and reason for a full-scale, roof-in-service demonstration of the performance of at least some self-drying roof constructions.

It is proposed that the proposed building have its roof consist of twenty or more types of insulated roof designs, each of 100 square feet area or more, and each instrumented with heat-flow devices, thermocouples and recording systems, to enable continuous observation of insulating performance, and drying performance when wetted in simulation of a roof leak. A few designs will be of the conventional kind with a vapor barrier, for comparison under the same conditions with the others of selected self-drying design. The interior conditions of the building will be controlled to simulate normal air-conditioned occupancy; the exterior would be subject to local weather conditions. To analyze the recorded data, obtained under the transient conditions of weather exposure, use will be made of processing by digital computer. Two chief objectives are sought: an in-service comparison of performance of self-drying versus conventional insulated roof designs and an in-service evaluation of the limiting values of certain criteria for design of self-drying roofs already developed in the small-scale laboratory investigations which, if confirmed, provide a basis for performance specifications for such constructions. Some laboratory determinations of thermal and moisture properties of component materials will be necessary. The minimum time for observations is estimated to be at least two winters and three summers, with additional time for preparation and instrumentation and for summarization of results.

The design of the experiments consists of eighteen constructions identifiable by numbers and arrangement in Figure 3. Construction spaces 19 and 20 are reserved for new designs available subsequent to reporting of the laboratory data. The constructions are:

No. 1. Deck - 4 inch thick, monolithic, steel reinforced concrete

- No Vapor Barrier

- Insulation - 6 inch thick perlite aggregate insulating concrete, 30-40 lb/ft^3 oven-dried

- Built-Up Roll Roofing

No. 2. Deck - Concrete same as No. 1

- Asphalt Vapor Barrier

- Insulation - 1-1/2 inches thick glass fiber insulation board.

- Built-Up Roll Roofing

No. 3. Deck - 3 inches thick pre-cast perlite aggregate plank; minimum of 3 feet wide, steel mesh reinforced; concrete 30-40 lb/ft^3 oven-dried.

- No Vapor Barrier

- Insulation - 1-1/2 inches thick glass fiber board

- Built-Up Roll Roofing

No. 4. Deck - 1-1/2 inches thick glass fiber formboard between steel bulb-tees

- No Vapor Barrier

- 2 inches thick poured gypsum concrete

- Built-Up Roll Roofing

No. 5. Deck - Kraft-paper steel-mesh

- No Vapor Barrier

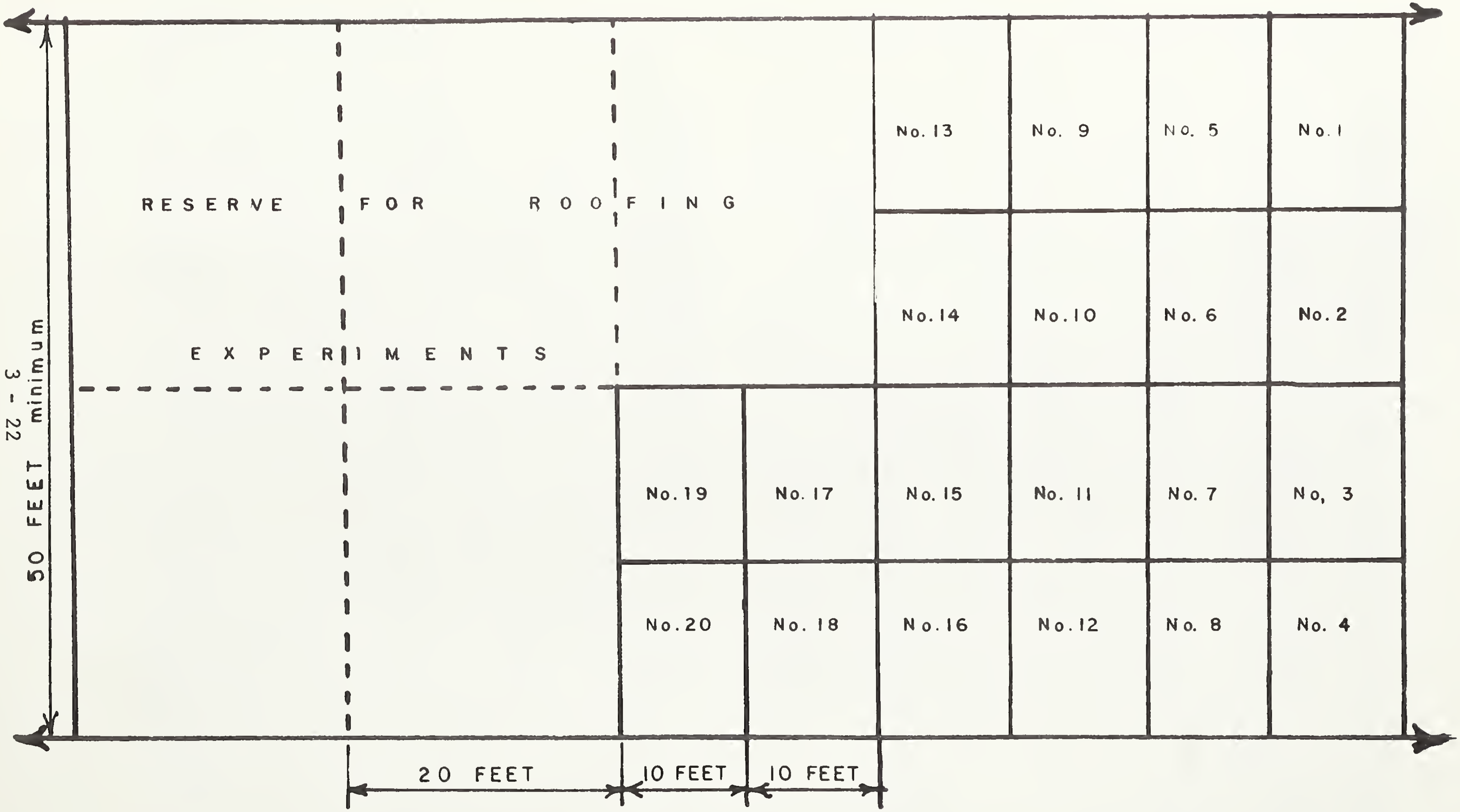

Figure 3. INSULATED FLAT ROOF SYSTEMS

- Insulation - 6 inches thick perlite aggregate concrete, 30-40 lb/ft^3 oven-dried density

- Built-Up Roll Roofing

No. 6. Deck - 2 inches thick wood-fiber formboard insulation between steel bulb-tees

- Built-Up Roll Roofing

No. 7. Deck - 3 inches thick pre-cast perlite aggregate plank; minimum of 3 feet wide, steel mesh reinforced; concrete 30-40 lb/ft^3 oven-dried

- No Vapor Barrier

- Insulation - 1-1/2 inches thick wood-fiber board

- Built-Up Roll Roofing

No. 8. Deck - 1-1/2 inches thick wood-fiber formboard between steel bulb-tees

- No Vapor Barrier

- 2 inches thick poured gypsum concrete

- Built-Up Roll Roofing

No. 9. Deck - 1-1/2 inches thick glass fiber formboard between steel bulb-tees

- No Vapor Barrier

- 3 inches thick perlite aggregate concrete without reinforcing, 30-40 lb/ft^3 oven-dried.

- Built-Up Roll Roofing

No. 10. Deck - 2 inches thick pre-cast gypsum concrete plank; minimum of 3 feet wide and steel mesh reinforced.

- No Vapor Barrier

- Insulation - 1-1/2 inches thick glass fiber board

- Built-Up Roll Roofing

No. 11. Deck - 3 inches thick coarse wood fiber-cementitious binder board insulations on a steel frame

- Built-Up Roll Roofing

No. 12. Deck - 3 inches thick coarse wood fiber-cementitious binder board insulation on a steel frame

- No Vapor Barrier

- 2 inches thick gypsum concrete

- Built-Up Roll Roofing

No. 13. Deck - 1-1/2 inches thick wood-fiber insulation board formboard

- No Vapor Barrier

- 3 inches thick perlite aggregate concrete, no reinforcing, 30-40 lb/ft^3 oven-dried

- Built-Up Roll Roofing

No. 14. Deck - Steel deck

- No Vapor Barrier

- 3 inches thick perlite aggregate concrete, no reinforcing, 30-40 lb/ft^3 oven-dried

- Built-Up Roll Roofing

No. 15. Deck - Steel deck

- No Vapor Barrier

- Insulation - 1-1/2 inches thick glass fiber board

- Built-Up Roll Roofing

No. 16. Deck - 3 inches thick pre-cast perlite aggregate concrete, 30-40 lb/ft^3 over-dried, steel reinforced; minimum 3 feet wide planks

- No Vapor Barrier

- Insulation - 1 inch thick expanded polyurethane plastic

- Built-Up Roll Roofing

No. 17. Deck - 2 inches thick gypsum concrete plank, steel mesh reinforced, minimum 3 feet wide

- No Vapor Barrier

- Insulation - 1-1/2 inches thick wood-fiber board

- Built-Up Roll Roofing

No. 18. Deck - 2 inches thick gypsum concrete plank, steel mesh reinforced, minimum 3 feet wide

- No Vapor Barrier

- Insulation - 1 inch thick expanded polyurethane plastic

- Built-Up Roll Roofing

No. 19. Reserved for new insulated roof systems.

No. 20. Reserved for new insulated roof systems.

The periphery of each of the above constructions must be water-tight and incorporate expansion joints. The planned procedure is to measure the performance of each construction as installed for the four seasons of the first year and later deliberately add water to the insulations in simulation of a roofing leak and again measure the performance over the four seasons of the year. The constructions will require a special structural support system designed to accommodate the different thicknesses of constructions. The quantities to be measured at regular intervals are heat flow, temperature, indoor temperature and relative humidity or dewpoint and outdoor weather. The methods for these measurements are developed. Additionally, a moisture content history is needed for each construction. Methods for continuous automatic measurement of moisture content are not developed. Selected methods will be used to develop in-situ means. A procedure of sampling the constructions over periods of time and drying the samples in an oven to determine the moisture content history is planned. Supplementary photographic and visual data will be obtained. Close supervision of the construction will be required and considerable testing to determine as-installed physical properties will be needed.

6.1.4 Flooring Experiments

The objectives of the flooring experiments are to determine what treatments are effective and necessary for controlling the effects of sub-floor moisture conditions for slab-on-ground constructions and to compare the performances of various types of floor coverings. In addition, the rate of moisture transmission of various types of concrete slab constructions and the rate of heat transmission through the slabs for various temperature and moisture conditions will be investigated.

A continuing trend both in this country and abroad is to build basementless buildings. There is a need for more complete information on concrete slab-on-ground constructions with various floor coverings with respect to heat losses for various sub-floor moisture conditions. Satisfactory answers to questions on the construction of gravel beds, the use of vapor barriers, the type of concrete, and the performances of various floor coverings and adhesives are needed. Data obtained experimentally under controlled service conditions are necessary to provide a sound basis for decisions on economical slab-on-ground constructions.

The design of the flooring experiments consists of several concrete slabs on earth or gravel beds with facilities for controlling surface-temperature of the slabs and temperatures and water levels in the soil under the slabs. Water levels will be adjusted to simulate drained and flooded soil conditions. Means for measuring heat flow through the slabs and procedures for evaluating the performances of various kinds of floor coverings and adhesives will be incorporated. A sketch of a proposed layout is given in Figure 4. Suggested slab constructions, each of about 100 square feet in area and 4 inches in thickness, consist of the following: (1) concrete slab over six inches of fine (bank-run) gravel, with paper separator between gravel and slab; (2) same as (1), but with coarse (3/4inch plus) gravel; (3) same as (1) with about six mil polyethylene membrane vapor barrier in place of paper separator; (4) slab on earth with no paper separator; (5) same as (4), but with six mil polyethylene membrane vapor barrier on earth under slab; (6) same as (4), but using a concrete, made water repellent by an admixture. The above slab construction arrangement will enable direct comparisons between designs over fine (1) and over coarse gravel (2), and between these and a floor directly on earth (4). Further, the effects of a vapor barrier under slabs over gravel (3) and over earth (5) can be compared. Finally, a slab (6) on earth with water repellent treatment is included for additional information. Comparisons will be based on findings as to both heat flow and the effects on the floor coverings.

The procedures planned include selection of a soil considered to be typical, and use of currently used design procedures, inculding an estimate of heat losses on the basis of currently available data for later comparison with in-situ performance. Electrical heating will be incorporated in the slabs to determine heat flow under conditons of flooded and drained soil, for a range of controlled slab and soil temperatures.

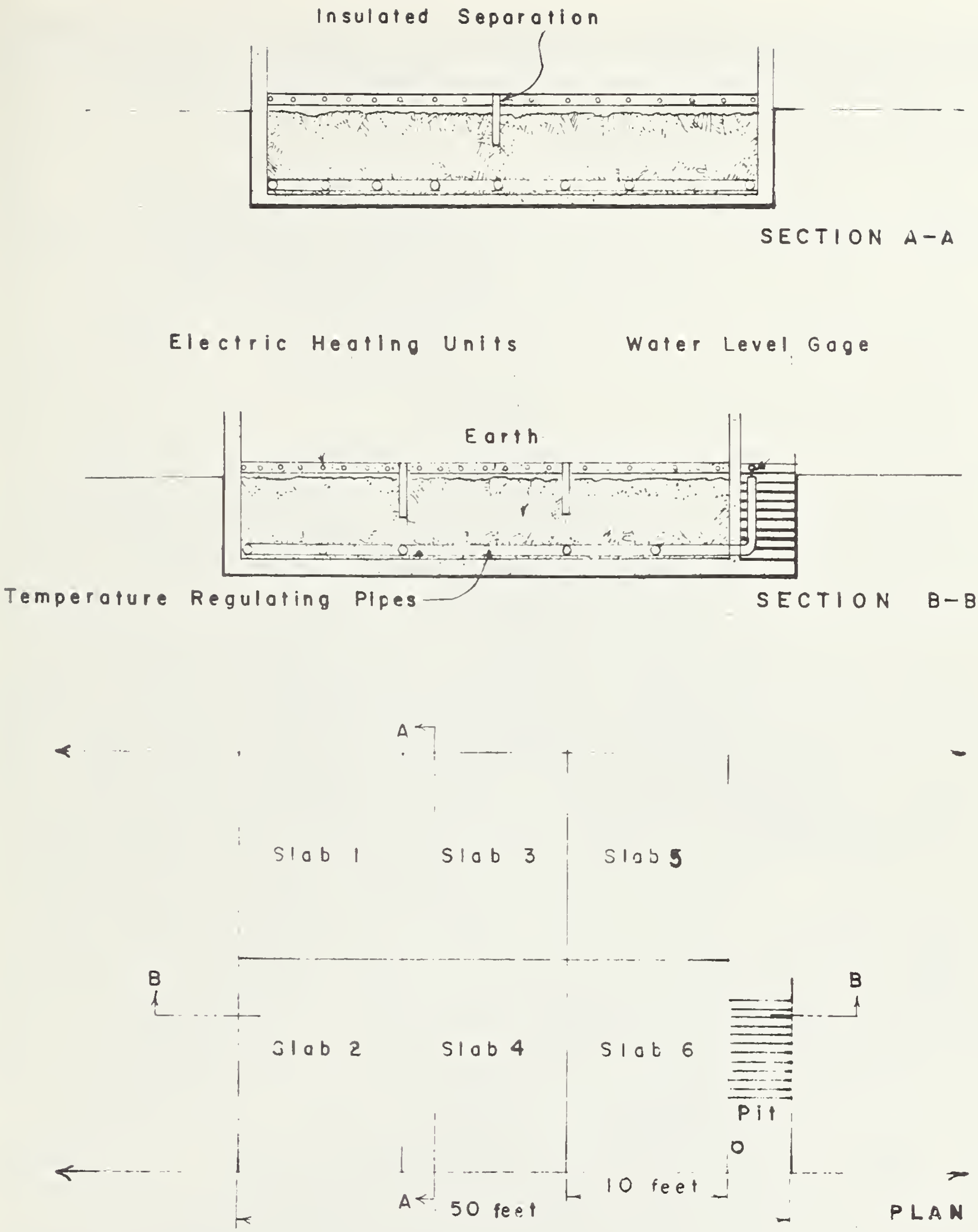

Figure 4. FLOORING ENGINEERING EXPERIMENTS

A study of floor coverings, adhesives, and methods of application and time of application will be made using square samples of materials about 27 inches or more on a side. Replications of some applications will be used to compare results among the different slab constructions.

The methods of measurement and instrumentation are largely developed. Quantities to be measured include heat and moisture flow rates, temperature, moisture content by sampling and oven-drying, plus a variety of flooring properties that will be measured on duplicate samples of materials in the laboratory. Supplementary visual and photographic data will be used.

6.1.5 Wall Experiments

The objectives of the wall experiments are to measure simultaneously over a period of time the key performance characteristics of walls of several types, each of full-scale dimension and exposed to natural weather conditions outdoors and to normal occupancy indoor environment, and to compare the in-situ performances with performances expected at the time of design.

Much attention has been given to the design and construction of the walls for buildings. One compelling reason is that the total cost of walls for buildings per square foot, including partition walls, is usually greater than costs for the roof or floors. Literally dozens of materials are available for incorporation into the design of a wall. Written specifications of requirements of strength, finish, etc., as determined by specified laboratory test procedures, are readily available for each material. Not so readily available, but much needed, are quantitative and definitive statements of the engineering performance required of the total wall system before a designer begins to select candidate materials. Some progress has been made in these regards and in the development of laboratory methods of test that simultaneously measure more than one property on specimen panels or segments of building walls. However, little information is available to the designer of the total in-situ performance of walls including those that had been subjected to extensive laboratory testing. The need for wall investigations is to determine in-situ, performance of all important engineering aspects that occur simultaneously in practice. For example, properties in regard to strength, water resistance, heat transfer, acoustical performance, wind-pressure resistance, etc., may influence each other in important ways and need to be measured simultaneously on a full-scale basis. Additionally, the field performance of each quantity can be compared with that obtained from individual tests of that quantity in the laboratory.

The designs of the wall experiments consist of those structural aspects as given under Structural Engineering Experiments, plus a series of heat, air, and moisture transfer studies, corrosion of wall ties in masonry constructions, observations of several types of caulking and sealing materials, observations and comparisons of the durability of exposed materials, resistance of wall surfaces and joints to wind and rain, and acoustical performance. The quantities to be measured include expansion and contraction, deflection, loads on walls, wind and rain forces and pressures, temperature, heat flow, relative humidity, moisture content, air infiltration, and a complete outdoor weather history including solar radiation.

The designs of the walls must be such as to accommodate the multiplicity of experiments to be incorporated and yet represent current design practice. Provisions should be made to include new design ideas. It is suggested that the front of the building, one of the short sides, face east and its exterior cladding be of windowless brick masonry to harmonize with surrounding buildings. This masonry wall can be designed to include a variety of masonry wall cross-sections including use of different mortars; those with and without air spaces; those whose cavities are filled with pouring types of insulations; the use or non-use of vapor barriers; board types of insulation placed near the exterior cladding, at mid-wall, and near the indoor finish; various types and thickness of insulation; several indoor finishing plasters, plastics, or other indoor finishing materials; a variety of metals and shapes used as wall ties for study of corrosion effects; and several types of caulking sealant materials. During construction the wall would be fitted, by NBS scientists, with a number of transducers that would be used to record the quantities as given above such as movement, temperature, heat flow, etc.

It is suggested that the longest walls of the building be identical in construction and face north and south. These walls should be made of prefabricated units, some as wide as 20 feet, capable of being removed individually from the outdoor side after construction is completed. Some walls should contain windows for a first and second story. Several wall cross-sections should be used in a fashion similar to that of the east wall. It is suggested that the west wall be composed of a multitude of constructions, each a minimum of about 100 square feet in area, and include designs that would be used for residential construction such as wood, metal and plastic drop sidings in different colors, etc. North, south and west walls would be fully instrumented similar to that of the east wall.

Most of the methods of measurement have been developed except those for in-situ continuous measurement of moisture content and for air infiltration and exchange. Procedures for the latter are available that will probably be suitable for obtaining quantitative data but possibly not continuously.

From the wall experiments much by way of actual performance results can be expected. For example, by comparison only, one could deduce which methods of joining and fastening work best; the optimum location and resistance of thermal insulation; whether the indoor film thermal resistance can be used as an in-situ heat flow meter to determine the total thermal resistance of a wall without knowing its construction and without destroying any part of the wall other than measuring its surface temperature; the usefulness of vapor barriers; in-situ determination of the thermal diffusivity of a wall; deflections and dimensional changes caused by cyclic temperature and moisture variations; major sources of air leakage and drafts; condensation effects; corrosion and short-term durability of materials; water proofing and closure performance of caulkings; heat gains and losses; illumination levels with and without indoor lighting on a year round basis; natural weather exposure for a variety of materials including concrete, metals, glass and plastics; acoustic performance on an unoccupied basis; and many other results that may be qualitative and based on photographs or other observations over a long period of time.

6.1.6 Heating-Cooling Load and Mechanical Systems Experiments

The objectives of the heating-cooling load and mechanical systems experiments are to evaluate one or more existing methods used to estimate the heating and cooling loads of the climatic exposure building. The actual heating and cooling loads of the building will be measured and compared with those estimated before construction. A similar procedure will be followed in respect to the design and specification and in-situ measurement of the mechanical systems that respond to the actual hourly heating and cooling loads in order to maintain a prescribed controlled indoor environment.

Several methodologies for estimating heating and cooling loads and mechanical systems requirements are available in publications of the American Society for Heating, Refrigerating, and Air-Conditioning Engineers and others. Much engineering judgment is required in this design process and insufficient valid data are available as to the in-situ performance of such systems after they have been installed in a building. Generally, when air conditioning systems fail to achieve objectives the failure can be classified as one of capacity of a heating or cooling plant, or proper selection of components, which depends upon the heating and cooling load estimate; one of distribution; one of control; or combinations of all three. The special building facility will uniquely provide an opportunity to evaluate presently-used design principles and criteria. Existing occupied buildings cannot be effectively used for this purpose because of obvious reasons, such as interference with the intended use of the building, lack of a central instrumentation system, inability to make system modifications as needed, difficulty in using installed proprietary packaged items to provide information relating to principles rather than proprietary item performance, and limitations on ready access of professional personnel directly involved with the investigation.

Mechanical systems for producing and controlling the desired indoor environmental conditions are much affected by the outdoor weather. The non-steady character and extremes of weather may contribute heavily to failures of such systems particularly when they use copious quantities of outdoor air. Experience in large government housing projects has indicated a need for investigation of effects of weather variations for extended periods of time to determine the realistic performance of heating and cooling systems.

Detailed planning of the heating and cooling load and mechanical systems experiments is dependent on the nature of some of the other experiments with walls, roofs, and floors that may entail unusual factors of air leakage, moisture or heat transfer. However, the major quantities to be measured can be given as, temperature, pressure, fluid flow, heat flow, time, electric power, voltage, current and frequency, linear displacement and speed, rotative speed, relative humidity, noise, vibration and a complete weather history. The performance of air-cleaning systems incorporated in the mechanical system can be measured. Provision can be made to observe new designs and ideas such as those that combine the heating, ventilating and lighting functions into one unit or process. Methods of measurement are developed and available for these experiments.

6.1.7 Weather Recording and Analysis

The objectives of the weather recording and analysis experiments are to specify an instrumentation system and measure the micro-climate surrounding the building continuously 24 hours a day for a minimum period of 5 years.

Detailed definition of the weather surrounding the building is a key need in this project. The broad objective of determining the response of the building fabric to varying weather conditions against the fixed indoor environment requires a detailed knowledge of the weather in-situ. Information is available from the Weather Bureau-but this information applies, strictly, to the weather as measured at a given location in or near large cities (usually at local airports). It is expected that the information obtained can be utilized in other geographic locations whose weather history patterns are similar to those obtained in this project. As mentioned earlier, it would be desirable to conduct these same experiments at locations whose weather patterns are different from those of the Washington, D. C. area such as hot climates (Florida or Arizona) and cold climates (Minnesota or Maine), but the cost would probably be prohibitive.

The design of the weather experiments consists of using those weather measuring instruments and systems that are commissioned by the Weather Bureau. These are very well defined and specified (volumes of information are available) and instruments are obtainable by purchase. In addition, other instruments and measurement systems that are not formally commissioned will be used and some may require laboratory check or development. For example, a method or transducer that will monitor a surface to indicate and record what time periods the surface is wet, dry, or snow or ice-covered, is desired especially for roof areas. All recorded data will be computer processed and a daily weather history provided for use in the analysis and evaluation work of all other experiments in this project.

6.1.8 Field Measurement Techniques

The objectives of the in-situ methods of measurement experiments are to identify and develop techniques of measurement not presently available for in-situ use.

Presently available are many methods of measurement from NBS, ASTM, USASI, etc., that are primarily useful in the laboratory. Some of these techniques are suitable for field use while others need refinement. The need for measuring various quantities in the field under dynamic conditions is well known. For example, the determination of moisture content within concrete in the field requires insertion of a transducer into wet concrete before it sets during construction. Contact between liquid water and transducers often destroys the usefulness of the transducer or radically changes its calibration. Similarly, in heat flow much of the measurement is done under static conditions of constant temperatures but, in-situ, dynamic conditions prevail.

The plans for in-situ experiments are to utilize those methods of measurement known to be suitable for field use and at the same time incorporate into experiments new and hopefully simpler, less costly, means for obtaining reasonably precise in-situ data. Several variables and methods have been mentioned in descriptions for all experiments in this project and as details develop others will become identifiable. A considerable amount of preliminary laboratory evaluation of a measurement idea or system may be required before it is actually installed in the building.

6.1.9 Building Construction under Inflated Balloon

The objective of this experiment is to utilize the technology of inflatable buildings as a pilot investigation of the problems and benefits of constructing permanent buildings inside a temporary inflated envelope.

One of the needs of the climatic exposure investigations is to avoid the effects of weather on the components of the building during its construction to assure the materials installed are in a condition as is normal in use, i.e., not excessively wetted or exposed to prolonged effects of freezing and thawing. Further, it is well-known that architects, engineers, contractors, and construction workers are hampered by winter-time weather conditions which ultimately increase the costs of buildings. If a construction technique were available that would be truly independent of the weather it may be possible to effect savings from more efficient scheduling and from the effects of down time and loss of momentum of construction crews. Further, a guarantee of year-round work for construction crews could become technically feasible. The military uses inflatable buildings for various purposes, such as assembly areas for helicopters, portable hospitals, etc. The technology is such that these buildings can be made to cover reasonably large areas and can be fitted with air-curtain doors or openings that would permit passage of trucks or materials. There are questions concerning the use of inflatable buildings for construction. These deal primarily with the safety of the environment between the plastic bubble and the building under construction since the construction process generates noxious gases, dust and dirt, noise, etc., from a variety of activities.

The design of this experiment is to erect an inflatable building of a size sufficient in volume to generously cover the permanent building to be constructed within-during a winter season. The environment within the bubble would be measured to determine its nature and it would be continuously monitored for safety. Records would be kept of construction time and cost for comparison with normal construction procedures, to determine if savings are possible. Upon completion of the construction of the permanent building, the inflatable building would be removed and measurements on the permanent building and its environments would begin. The planning for this experiment is in its early stages and cannot be described in detail until a better definition of the permanent building is obtained, and until more details about the inflatable balloon itself are available.

6.1.10 Moisture Content History of Buildings

The objectives of the moisture content experiments are to determine the moisture content history of all major structural elements of the building from the time of construction and to evaluate this information in regard to its general applicability to the intelligent estimation of a building's ability to withstand the effects of accidental fires (i.e., its fire endurance period). It is anticipated that this total moisture content picture of a whole building will provide significant contributions toward the analysis of shrinkage, deflection, air leakage, acoustic, and cooling load data obtained in other experiments.

The fire behavior of building materials and structures is significantly dependent on the moisture content when the specimen is subjected to test. In spite of this, there is only the most meager quantitative information available on the spatial distribution and seasonal variations in moisture content of such materials in service over an extended period of time. A complete moisture history of a building is needed to evaluate the aging periods necessary to approach steady-state conditions as a function of material type, thickness, and location, and to correlate moisture content with mechanical (shrinkage, cracking, etc.), thermal and chemical performance. Also, badly needed is an in-service evaluation of suitable types of moisture-sensing elements methods.

The design of the moisture content history experiments consists of using small probe-type gages to measure relative humidity in selected structural elements, made from representative building materials, at depths of one, two, four and eight inches below the internally exposed surfaces, as a function of time after placement of the element in position as a part of the building. Such measurements may be used to estimate the approach to moisture content equilibrium as well as the presence and location of local moisture gradients and moisture migration during the drying process. However, such "equilibrium relative humidity" values cannot be considered as substitutes for direct moisture content measurements, primarily because the relation of moisture content to relative humidity for many construction materials is not adequately known. It will therefore be necessary to remove samples at several selected locations of the structure periodically and to determine moisture content and moisture distribution by direct drying and weighing. This will be done by using a diamond core drill of about one inch in diameter to remove cylindrical samples of appropriate lengths and filling the hole with an appropriate material of similar hygroscopic properties. The sample removed can be quickly crushed and placed in a small closed jar to reach moisture content equilibrium at a controlled temperature. After measurement of the final equilibrium relative humidity in the jar, the sample can be dried in an oven to determine its moisture content. Where moisture content distribution in an element is desired, the cored sample is divided into an appropriate number of smaller cylinders, each of which is handled separately.

For fire resistance purposes, such measurements are needed in all structural parts of the building that are greater than 2 inches in thickness. Tubes or similar holders for moisture gages should be installed during the casting process, particularly if the structural member is reinforced and pre-tensioned. The number of sensing elements and their locations cannot be stated until the design of the structural members is completed.

The data gathered in this experiment is needed and would be complementary to the evaluations primarily concerned with roofing, self-drying insulated roof decks, floors, walls, acoustics and probably all experiments being conducted on the building.

6.1.11 Architectural Acoustics Investigations

The objectives of the acoustic engineering experiments are to measure the in-situ acoustic performance of the climatic building facility including measurements of structural vibration, e.g., from roof to basement; airborne and impact sound transmission through floors (from basement to 1st and 2nd stories); airborne sound transmission through wall constructions as a function of cracking, installation, etc.; and noise transmission and radiation of exterior walls (especially prefabricated metal panels) as a function of contraction, expansion, popping, sealing, etc., due to changes in weather conditions.

The problem of noise in buildings can be classified generally according to the sources of undesirable sounds; those generated outdoors and transmitted to the indoor environment and those generated indoors from building occupants and building services such as mechanical equipment. Often the problem of design for noise control is considered as two parts; one which treats the architectural and structural aspects of the design, and a second which treats separately the mechanical equipment aspects. In service, architectural, mechanical, and occupant aspects of the problem occur simultaneously. Little information regarding simultaneous interaction of these aspects is available. However, it is much needed to allow a systems analysis of the total noise environment of a building interior. It is proposed to instrument the climatic building facility to determine the interaction of outdoor and indoor sounds and the effect of the building fabric on this interaction. First-hand knowledge of the details of the building fabric and mechanical systems becomes a necessity for acoustical analysis.

Initially the building should be without occupants to eliminate the variable of noise generated by people. Later, perhaps, additional data for comparison can be gathered on the same building with occupants.

The design of the acoustic experiments consists of installing vibration pick-ups and microphones in strategic locations throughout the building and outdoors. Data concerning temperature, relative humidity, linear movement and weather will be needed but these will be available from other experimental investigations in the building. The precise numbers and locations of acoustic transducers cannot be stated until the size and details of the construction are finalized on architectural construction drawings. It is planned to incorporate an impact or foot-fall experiment at the threshold of buildings. Also, from time to time, known sound sources will be used outdoors and indoors to obtain comparative performance data. It is expected that all transducer signal-data will be recorded automatically and processed for analysis.

All instrumentation is currently obtainable commercially.

6.1.12 Instrumentation and Data-Handling

The objectives of the instrumentation and data-handling experiments are to investigate the suitability of the several commercially available instrumentation systems for use in a central data gathering and control function for the climatic building facility, to prepare specifications for the purchase of such equipment, to acquire the equipment and perform suitable operational tests in the laboratory before it is installed in the building, to operate the equipment during the service life of the project, and to supply computer processed data to all experiments in a form suitable for analysis and evaluation.

The need for a rapid automatic data gathering and processing system is technically as well as economically based. To satisfy the need for data that would indicate the instantaneous performance of the total building and its environments, each individual experiment must be read out rapidly and accurately. It is estimated that the instrumentation system should be capable of recording signals, both a.c. and d.c. types, from about 2000 transducers in as little as six minutes. Flexibility and versatility in operation are important to accommodate changes as they need to be made. Literally, millions of bits of information will be gathered over the five-year life-span of the project. To accommodate separation and reduction of these data into meaningful and understandable performance, computer processing is indispensable. To do this it is obviously more economical to operate a data gathering system that will accommodate perhaps a dozen major experiments as compared to each experiment operating its own individual data-recording system.

Selection of the design of the instrumentation and data handling experiment consists of study of the state-of-the art of commercially available equipment for use in this project, including meetings with engineers from instrumentation companies and visits to field sites where various kinds of systems are in service. This phase of the experiment is essentially completed. Present thinking for the overall system considers favorably the use of a "real-time" or "on-line" computer. A real-time computer has the advantage of being able to make calibration corrections and corrections due to non-linearity to the information logged by the acquisition system, and to look up table values. It also serves as a control mechanism for the system. It can feed back signals that order priority, sort data into experimental categories, and allow signals to be used only when needed. One of the difficult choices involves sampling techniques. For any reasonably large experimental operation there will be many situations where signals will be sampled about once every second, but there will be others where the sampling rate is once every half hour or even once every day. Two alternatives are available from manufacturers. One suggests that the on-line computer does the scanning, that there be no electrical scanners in the system whose scanning rates, once set, faithfully log information at a preset rate for a large number of transducers. For this method soft-ware programming can instruct the computer to sample each transducer at a different rate from other transducers. The other alternative suggests that all transducers be scanned by electrical scanners at fast preset rates: one large block, for example, at once every second, and another large block at once every minute. Under this plan many of the unneeded signals must be discarded and there will be large redundancy, but it may, upon analysis, be found to be less expensive as compared with the costs of programming the computer. Preliminary studies for the alternatives are underway and the final choice necessarily must fit the budget available for instrumentation. A final number of transducers awaits detailed specification of number, type, and location, on design drawings of the building. A tentative sketch of an instrumentation plan is shown in Figure 5.

This sketch shows electrical scanners. It shows also with each scanner a block representing a conditioner. The conditioner will include such devices as an automatic reference junction for thermocouples being scanned, a constant-current device for supplying excitation voltages for transducers such as strain gages, and a zone-box which usually consists of an insulated metal block to keep connections in thermocouple circuits at constant temperature so that no extraneous voltage is generated. Conditioner costs can be large and a way needs

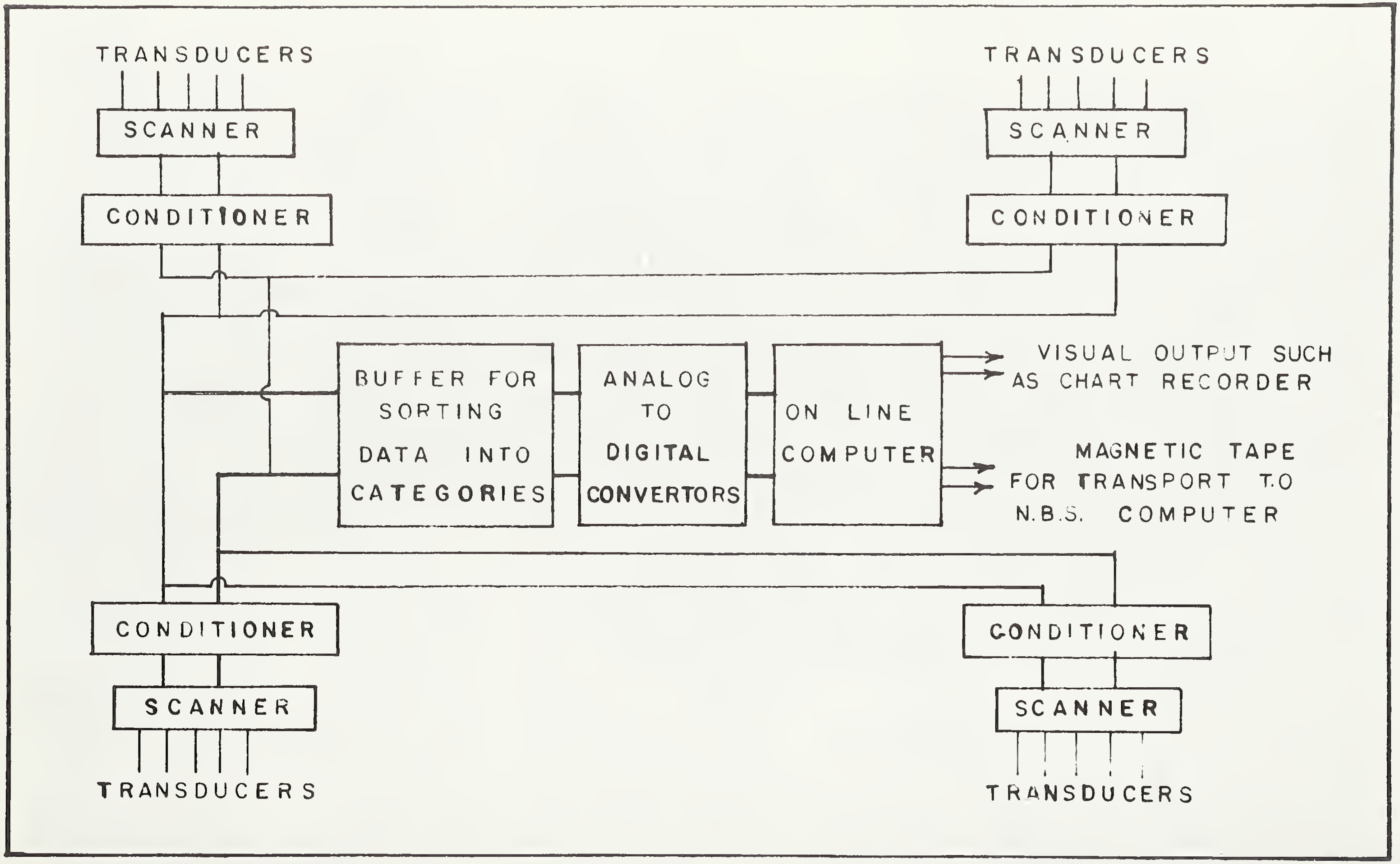

Figure 5. SCHEMATIC OF DATA ACQUISITION SYSTEM FOR CLIMATIC FACILITY

to be devised for each conditioner to share a large number of transducer lines. The memory of the computer will store the data and periodically "dump" to magnetic tape, but the out-put of an on-line computer will not be in a final reduced and collated form. The data on the magnetic tape will be manually transported to the NBS computer center for reduction. Rental of the total acquistion system may offer economic advantages.

The next phase of the instrumentation experiment is to prepare specifications for the type of system selected. Much information for this phase is at hand but awaits implementation after policy and budget decisions are made. Proper preparation of specifications for a system will require considerable effort. Other phases of the data acquistion, laboratory checking, installation, operation, computer programming, and coordination of these efforts, are planned but can be implemented only as budgetary and man-power situations permit. Service contracts on instrumentation are mandatory.

6.2 Priorities of the Proposed Projects

The relative importance of the projects just described has been considered. The incremental cost of adding or subtracting any one of the thirteen experiments considered for inclusion in this facility would be exceedingly small in comparison to the total cost, thus an ordering of experiments in terms of priorities is not deemed advisable.

7 Cost Estimate

7.1 Design and Construction

Construction	$500,000
Site Preparation	100,000
Interruption for Instrumentation	50,000
Contingency, 10%	65,000
A & E Fees	65,000
Total	$780,000

7.2 Instrumentation $250,000

7.3 Annual Operating Cost $240,000

8 Benefits of the Proposed Program of Research

For some of the investigations, estimates can be made as to prospective benefits. Investigations on roofings, and on self-drying insulated roofs, can each be seen to have potential savings possibilities on the order of several millions of dollars per year to the government alone, and about $500 million in private construction, simply by increasing service-life. Major benefits, not immediately translatable in dollars, include developing criteria, tests, and information suitable for defining and improving the performance of a building and its components and also revealing the relation between small-scale and full-scale tests. Performance findings should be immediately applicable for use in actual buildings without major questions arising about extrapolating the findings developed in laboratory tests to cover actual use applications.

The annual loss in the United States resulting from the deterioration of buildings, mostly caused by climatic exposure, exceeds $3 billion. The total cost of the research program including the construction of the special research facility is estimated at about $2,250,000. Many of the findings of this project could lead rather quickly to changes in construction which would reduce the deterioration of buildings. In view of the great need for adequate information on how to combat climatic-induced deterioration in buildings, it is anticipated that the annual benefits of this research could easily be 500 times as great as the total outlay of funds for the research.

9 Conclusion

An integrated program of research is one which would investigate and measure the effects of natural and service-imposed environments upon the performance of the building over a significant part of its life and the losses in performance effectiveness which would occur. Specific results of this investigation would be (1) a definition of the problems of deterioration which are a substantial part of the cost of building maintenance, (2) a recommended basis for the improvement of materials and methods of construction, (3) suggestions for the design of more durable and effective buildings and subsystems, and (4) the development of performance criteria for its subsystems. The needs and objectives are real and valid. It is recommended that an NBS program be established and funded to implement the design and construction of an NBS climatic-exposure research facility and to conduct the experiments enumerated herein.

CHAPTER 4

Architectural Acoustics

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Architectural Acoustics

1 Executive Summary

The magnitude of the problems with unwanted noise in buildings and their environment, and the civic pressure for noise regulation and abatement spurred by the adverse effects of intruding noise on well-being and the conduct of tasks and social activities, are growing steadily. Sucessful acoustic design in buildings depends not only on the properties of building materials themselves, but upon the methods of assembly and structural support, workmanship, geometry of spaces, surface characteristics, and the utilization of interior furnishings. The building construction industry employs a large amount of natural materials such as earth, stone, and wood as well as sophisticated prefabricated elements made by assembly-line methods, and is a mixture of self-help enterprises, small businesses, building tradesmen, and large-scale manufacturers of building materials and components. The prospect of major improvement coming from acoustical work done by individual manufacturers of commercial products affecting noise is assessed as poor, because such work is marginal to the basic research and comprehensive fundamental information needed to improve acoustical technology and standards and because of the nature of the building industry itself. Some fundamental work is being carried out at about eight universities, but little of it is government-funded, or is reported in the literature.

At present, no program of significant scope in architectural acoustics is supported by the U. S. Government, and the U. S. research position is far behind the government-supported research in Canada, England, or Europe in both absolute and per capita terms, and probably behind that of Russia and Japan. In the past (since 1919) much essential fundamental research was done by the Sound Section of the National Bureau of Standards, but at present, architectural acoustics research at the Bureau is practically at a standstill because of lack of necessary modern laboratory facilities, of staff, and of funding for programs commensurate with needs. Thus, the needs of the U. S. Government and of the nation in the field of architectural acoustics are not being met, with respect to a) basic research; b) development and evaluation of testing methods, techniques, and standards for acoustical design and for product performance; c) needed support for the U. S. position in both national and international acoustical standardization; d) stimulation of industry to produce new products where basic research indicates they are possible or needed; and e) research in applied acoustics and noise control to keep pace with the growing mechanization of the U. S.

Considering basic problems urgently needing attention, ten important specific areas are listed, and the need for national and international standardizing activities is also discussed.

The nature and size of facilities required for a comprehensive program of architectural acoustical research are outlined, and their uses and applications are briefly described. Reasons why existing or private facilities for architectural acoustics research are not adequate for the needed program were explored. It was found that of twelve research capabilities identified as important to basic research or services needed in architectural acoustics only six, at most, are presently available in independent commercial or institutional testing organizations, or in industrial laboratories, in the United States. This review led to the conclusion that there is no adequate practical alternative to a comprehensive architectural acoustics research facility and program in the Building Research Division of the National Bureau of Standards.

In addition to its principal objective of advancing basic research in architectural acoustics, the program proposed would serve many other functions needed for the interests of the U. S. Government. It would provide the Government with the capability for evaluating acoustical products, services, and designs, and developing recommended practices, test standards and design requirements to avoid the great cost of remedial measures now often required to obtain satisfactory acoustical performance of buildings in which the Government has an investment or interest. Additional services of value both to the U. S. Government and the nation, include use of a mobile acoustic laboratory to guide research by relating acoustical problems and conditions in the field to laboratory measurements and methods, and to make field performance tests at specific sites to obtain information for research studies; assistance to governmental agencies on specific unique acoustical problems in which cooperation between outside consultants and the Government's capabilities would be desirable; and provision of information and referral services to Government, industry, and the public on a thorough and unbiased basis.

An estimate of costs for the needed facilities, and of annual operating costs, was developed. Location of the facilities, and the degree of commonality between them and other Building Research Division and NBS activities were considered.

Broad conclusions based on the review of the architectural acoustics needs of the United States, and of the appropriate program to meet them, were reached. The final conclusion was that no financially or professionally acceptable alternative to its proposals was found by this study.

2 The Noise Problem

2.1 Scope and Magnitude

There has been a tremendous increase in the awareness of noise on the part of a large segment of the population. This can be shown by:

(a) The large number of news items relating to noise problems that have resulted in private and public complaints to governmental authorities at all levels.

(b) The increase in the number of lawsuits involving noise complaints.

(c) An increase in the advertising which is noise related.

The sensitivity to noise complaints has led some manufacturers to redesign products to take advantage of the claim for a quieter product.

There is a major concern with noise problems at the national level. The Federal Housing Administration has written noise regulations into their present minimum property standards. Insurance companies, Public Health Service, General Services Administration, and military housing agencies have also established some noise control limits for housing financed or built for them. Each of these organizations is pursuing such activities without effective coordination with each other or with any national standard. Another example is in the measures that various members of the Congress have seen fit to introduce which would provide for the control of noise or which will provide funds to obtain more information on noise and in turn will permit more effective legislation.

2.2 Sociological and Acoustical Factors

The problem of noise is not, as often indicated by municipal officials, one of a few "cranks" complaining about their neighbors or some local industry, but is an integral part of our present sociological fabric. Noise, although it may not have any apparent immediate physiological or psychological effect on people, can interfere with normal human activity such as conversation, the audition of television, radio, and phonograph sounds, and with the simplest of creative tasks. Since these are the activities that are often associated with relaxation and releasing the tensions of the work day or week, noise can effectively interfere with the psychological and physiological processes needed to prepare people to face their daily tasks. In other contexts, noise can interfere directly with sleep and rest, with business communications, and with safety on the job. Thus noise and its control are deeply intertwined with the social, business and health needs of the nation.

2.3 Acoustical Treatment for Building Systems

The attention given to noise by manufacturers of acoustical control products and to noisy equipment which is quieted to meet the minimum public demand, is a small measure of what might be accomplished. The reasons for this appear to be deeply imbedded in various aspects of the nation's economy, and the inability of the investment that goes into noise reduction to show as immediately tangible value. Most manufacturers allocate a minimum of their product development budget for application research or product design for quieter products. Their engineering staffs and managements seem well insulated from the knowledge and concepts that would allow design of quieter products. Also in many cases the manufacturer must charge a higher price for eliminating something that the customer does not expect or want in the first place.

There are other cases in which the quieted device or appliance would cost no more than its noisy counterpart. The use of appropriate design might be all it takes. In some cases quieted construction and quieted appliances cost less than the noisy ones.

There are various commercial areas in which either lack of awareness of acoustic technology or the belief that the consumer will not pay extra for quieted products have retarded effective application of present techniques and capabilities to both old and new products. Commercial areas of major size include:

2.3.1 Acoustical materials (tiles, blankets, ceiling boards). These products contribute little that is architecturally desirable to the interior of a building. A few manufacturers have been able to integrate lighting and air-conditioning with some form of sound materials, but have contributed little to recent research and have devoted most of their efforts to product development. In the early days of acoustical tile, this product appeared as a panacea for all acoustical problems. It then became obvious to producer, salesman, and architect alike that tile has specific effective application areas. However, it still happens today that some over-enthusiastic salesman convinces an unsuspecting architect or builder that *his* new product is new and different from the ordinary.

2.3.2 Sound isolation products for architectural use. Typically, these products are partition and wall materials whose manufacturers include the major gypsum companies and the wood and hardboard panel manufacturers. As with the acoustical materials manufacturers, the industries in this category spend a considerable amount of money and "research" on product development, but put little time, money or effort into basic research. Products are advertised on the basis of existing standard test procedures, but none of these manufacturers has invested an adequate sum of money or much research effort at developing improved test methods or validating the existing methods. They appear to be willing to accept any standard which gives them both respectability and high rating numbers, validated or not. A recent comment by a major manufacturer's laboratory representative was to the effect that it was up to the testing laboratories to develop the new standards and prove them out with their own funds.

2.3.3 Systems and devices for acoustical privacy. Examples of these are the sound traps for air-conditioning duct systems, above-the-ceiling barriers where the acoustical material does not provide adequate sound isolation between visually separated spaces, caulking and sealing compounds to seal the perimeter of walls against sound leaks, and the windows and doors that are used to provide vision and access but which unless especially designed to eliminate sound transmission will vitiate the sound isolation of the most effective wall. Here again little research is evident, with industry funds going into product and sales development.

2.3.4 Heating, ventilating and air-conditioning equipment. (This includes the fans, pumps, blowers, cooling towers and the air handling system.) Manufacturers in this category have made slow but steady progress toward controlling noise in the large central station systems, and probably can design a quiet system if given a disproportionately large share of the design budget. The small manufacturer follows the lead of the major manufacturers. However, the packaged products show a notable lack of improvement. This appears to be a problem in both economics and professional responsibility. Most of the major manufacturers claim that there is no real demand for quieter products when the price of the quieter products is made known to the prospective buyer. Also the consulting engineer may reject the higher-priced unit that the owner might be willing to buy. Direct experience indicates that the cost problem arises because most manufacturers expect the first major purchaser to cover the product development cost on the first order. This is an unreasonable economic burden.

2.3.5 Integrated environmental systems. There has been little work, except in a few cases, toward integrating acoustical effectiveness with other aspects of environmental control such as lighting and air-conditoning. The few systems where steps are made to integrate acoustics into environmental control as a single system usually have resulted in products with an excessive price tag. It appears to be a problem of the lighting or air-conditioning designer not being able to expand his creativity into the acoustical area, and the acoustical designer not being adequately conversant with products for environmental design to really integrate the properties. Except in a few notable cases, what seems to have resulted is an expensive product which is an agglomeration of all the separate pieces required for each separate phase of environmental control instead of an integrally-designed product having a multiple function.

2.3.6 Home appliances. This area is one in which much needs to be done. Little of real worth has been done to quiet the many useful appliances in modern homes even to the extent of using the techniques presently available. The problem here appears to be two-fold. The aesthetic designers have no understanding of the possible effects on noise output of what to them is a simple change in styling or material; the mechanical-electrical designers do not appear to have a real understanding of the sources of noise in electromechanical equipment.

2.3.7 Mufflers and prefabricated sound-control enclosures. These are two highly competitive sound control product areas which are associated with both industrial noise and with noise in heating and air conditioning systems. In this field, too, there has been little basic research and no testing standardization. Almost nothing is known about the acoustical behavior of the mufflers under air-flow conditions, and the acoustical enclosure panels are sold on a unit basis with the sound absorption values and the sound isolation ratings not only taking a secondary place, but being of questionable value. This occurs because of the fact that at very high sound absorption levels existing standards do not provide a means of rating a material for either sound absorption or sound isolation. No effective research is going on in these areas at present.

This brief analysis of the existing manufacturing scene for noise control devices and systems indicates that there is too little money being spent for research on the acoustics properties of products (not product development) and that this is probably due to the small profit margin in these highly competitive items.

2.4 U. S. Government Needs In Architectural Acoustics

The U. S. Government itself has several specific needs associated with architectural acoustics. These include:

2.4.1 Standards and Design Techniques

Standards for and design techniques used in evaluation of government insured, sponsored or financed buildings for the residential and redevelopment agencies.

2.4.2 Proof-of-Performance

Evaluation or proof-of-performance test standards for material supplied to the U. S. Government.

2.4.3 Standards for Special U. S. Government Applications

Development of standards of adequacy of products needed for specific application in U. S. Government activities.

2.4.4 Testing Services

There is in the U. S. nowhere other than NBS to which government agencies and officials can turn for suitably documented information relating to problems in acoustics. Typically, there is almost no current knowledge on the effect of outdoor noise on site selection for hospitals. In the past, NBS personnel have known of practically all of such work, but continued documentation must be assured, and the information in the most recent document may be out of date when some new transportation system is introduced, a fact which would be known to NBS Architectural Acoustics personnel.

3 Status of Architectural Acoustics Research

3.1 Current Non-Government Research

Who is doing research and what kind of research is being done in architectural acoustics is the next obvious question. To answer the question, the Journal of the Acoustical Society of America was reviewed. It was noted that there have been fewer papers published in JASA on architectural acoustics and noise control in the last 10 years than for any other subject areas.

It is known that some fundamental research in these two areas is being carried out at:

Case Institute of Technology
Columbia University
Harvard University
John Carroll University
Massachusetts Institute of Technology
Pennsylvania State University
Purdue University
University of California at Los Angeles

Very little of this work is reported in the literature. A review of the Commerce Business Daily listing of contract proposals being considered and those awarded shows that there is little government-funded research outside of various military agencies' laboratories. Almost none of this work is in architectural acoustics or noise control.

In view of the meager basic research work going on in the United States, it should be clear that any standards work that is taking place is based on little or on marginal research.

A recent editorial reproduced below from Sound and Vibration magazine (July 1967) spells out clearly some of the current problems.

"RESEARCH AND PUBLICATION"

"There are three facets of research in vibration and airborne sound that continue to puzzle us year after year. The first relates to the subject areas selected for research. Second is the apparent lack of support for basic research among acoustical products companies. The third facet concerns publication of poorly done research and its corollary, poorly documented papers that may or may not report significant information.

"Our observations indicate that very little basic research is being done either at universities or in industrial concerns that make and sell acoustical products such as mufflers, ceiling tile, building components, vibration reduction systems, and shock suppression systems, to name a few. There is a lot of cut-and-try experimentation, but this can hardly be dignified by the name of experimental research. In addition, a large volume of application engineering is assigned to corporate research laboratories. This misses the mark, too. It simply is not research.

"Turning to academic research, we find many "research" projects supported by Federal grants. There are also numbers of published papers alleged to be reports of research. Some of these are clearly partial fulfillment of the requirements for an advanced degree. Others look like staff members' efforts to survive the "publish or perish" phenomenon. We should not overlook the publication of progress reports which are interesting since they usually deal with no progress. This leaves a few genuine research papers. But, where is work of the stature of that produced by Harvey Fletcher, W. P. Mason, or P. M. Morse and R. H. Bolt? Our present climate of Federally-funded university "research" and product development industrial "research" must be re-oriented to once again produce work of such depth and quality. For example, little theoretical information of value has been published on the use of reverberation rooms since the 1944 paper by Morse and Bolt. It is even more appalling that many authors use such rooms for transmission loss, sound absorption, and sound power measurements that are not only of questionable validity but are theoretically indefensible.

"A review of references or obviously omitted references is also illuminating. One easily-detected category is the "new look at an old subject" which was preceded by identical papers in another related field. Lack of a reference to earlier work indicates to us that the author really did not go through the literature. Another category contains what might be termed the "company references only" paper. Here the author lists only those papers published by his colleagues or predecessors in the company or institution. Typically, where a colleague has referred to Rayleigh in a 1930 paper, we find not the original source, but the "in house" reference. Of course, there is no regard to the fact that such "in house" publications are virtually inaccessible. A second class in this category is the "author references only" paper. Here we find a list of the author's prior work often referring to topics more fully covered in other material. In some cases, indeed many, references to the author's own work are well justified, but basic references should be repeated.

"Disquieting conclusions present themselves after our review of current published work and projects in acoustical research:

"Problem solving, not basic research, appears to receive the most attention and money in industrial and university research facilities.

"Published work is often accompanied by inadequate references. Careful literature search no longer appears to be one of the basic precepts for modern acoustical research in spite of the fact that the use of adequate reference material, and the documentation of such use, is of great value. It assists a reader in orienting himself, reduces further research on the subject and simplifies analysis and discussion of the paper itself."

3.2 Current U. S. Government Work

Who in the government is doing architectural acoustics and standards work research? There appears to be no one engaged in research in architectural acoustics and noise control within the Federal government. The work on standards is being carried forward by personnel from ESSA, NBS (with some interest and support by PHS) and FHA. However, none of the agencies appear to have budgeted sufficient funds to explore any of the major testing problems except on paper. At present, NBS has at Gaithersburg no facility for running sound transmission loss (isolation) tests or tests on mufflers, or in any way validating or disproving the validity of any proposed test method. In fact the U. S. Government is far behind government supported or implemented research in Canada, England and Europe, and is probably currently behind the level of activity in Russia and Japan on basic theoretical and analytical research in architectural acoustics.

3.3 History of Architectural Acoustics at NBS

The history of architectural acoustics in the United States is, except for its initial inception under Professor Wallace Clement Sabine at Harvard University at the beginning of the century, centered at the National Bureau of Standards. As a review of the literature will show, much work was done during the 1930's throughout the country, but landmark papers were produced throughout this period by Bureau personnel. A brief outline and bibliography are included in Appendix A to show the major contributions made by a perpetually understaffed Sound Section at NBS.

The National Bureau of Standards was organized in 1901. Although some work in acoustics was carried on a few years later, the Sound Section of the Bureau was not established until about 1919. For a period of two or three years following the close of the World War, a large portion of the work of the Sound Section dealt with the numerous problems of sound ranging and ballistics.

Although the staff of the newly formed section was small, it undertook investigations covering a broad spectrum of the field of acoustics ranging from studies in ultrasonics, hearing aids, microphone and transducer calibrations, electroacoustic instrumentation and audiology to infrasonics dealing with very low frequency sound and vibration.

During these early years, there were many inquiries from governmental agencies, architects and others about the sound insulating value of different building materials and types of construction. This increasing interest led to the development of a program in architectural and building acoustics and, subsequently, to the construction of the sound laboratory building in the Spring 1922.

Most of the subsequent work was oriented toward measuring the sound transmission loss of various types of wall and floor constructions and development of new or improved methods of test. The results of this work culminated in the publication of some classic papers by Buckingham, Chrisler, London, Cook, Waterhouse and others. In the course of time not only were techniques of measurements improved but new acoustical instruments were developed and as a consequence the state of the art was advanced substantially.

Concurrently with the above work, investigations of the absorption of sound of various building materials such as acoustical tile were undertaken. Because of the inherent defects of using the impedance tube technique for sound absorption measurements, a large 15,000 cubic foot reverberation chamber was built in 1928. This chamber and the associated method of test substantially increased the accuracy of measurement and the size of the test specimen. Further, the chamber was used for extensive investigations of the properties, characteristics and behavior of diffuse and reverberant sound fields.

These investigations resulted in the publication of other classic papers by Cook and Waterhouse which greatly advanced the understanding and use of reverberant sound fields and consequently the precision of measurement of not only sound transmission and absorption determinations but also of the sound power output of various types of noise sources.

Although much of this work was of a basic or fundamental research nature, a considerable amount of work dealt with noise problems of an applied nature, such as sound isolation for apartment buildings and noise reduction in airplane cabins. The numerous publications on room acoustics, acoustical materials, sound insulation of apartments and acoustical performance ratings of over 1,500 types of building materials and constructions were of great service to governmental agencies, the building industry, architects and builders. More than 75 major papers on architectural acoustics have been published by the Sound Section since it was established. These are listed in Appendix A. This is an outstanding achievement in light of the fact that during these years the average yearly budget supported approximately two men per year.

Along with this heavy schedule of research and testing, the staff was actively engaged in work of an advisory or consultative nature. It served, for example, as acoustical consultants to governmental agencies and on numerous occasions has given consultation, assistance, advice and technical information on acoustics and noise problems to the building industry, industrial associations, educational institutions, national and international laboratories, architects, builders and the public at large. These services covered a broad spectrum of architectural acoustics dealing with domestic, industrial, military and community noise problems. Further in support of the Bureau's mission and active interest in national and international standards, members of the staff served on the technical writing committees of various standards organizations, such as the American Society for Testing and Materials, ASTM, and the United States of America Standards Institute, USASI.

In recent years the staff has been engaged in devising appropriate acoustical test standards for both laboratory and field use, formulating sound insulation criteria for apartment buildings and developing techniques for the control of noise in such buildings. The results of most of this work which was sponsored by the FHA culminated in the preparation of a comprehensive 420 page book entitled "A Guide to Airborne, Impact and Structure-Borne Noise Control in Multifamily Dwellings" which will be published shortly under the FHA letterhead.

Although it might appear that a vast amount of work by the architectural acoustics staff has been done, its sum total effort has barely scratched the surface of the work that needs to be done in light of the ever-increasing noise problems which today are of serious national importance. These problems will double in severity and intensity within 10 years as the rapid progress in mechanization, development of new transportation systems and the emergence of new building materials and constructions continues to outrun advances in the technology of noise control.

It is fruitless to hope that any progress can be made in keeping abreast of the national noise problem, much less overcoming it, with the present architectural acoustics budget which barely supports a one-man staff operating the existing small, restricted laboratory facilities which have been obsolete for the past 20 years. The U.S.A. effort is most embarrassing when compared to that of Canada, a country with less than 1/10 the population, which has modern architectural acoustics laboratory facilities and a staff of between 10 and 15 scientists and technicians. The U.S.A. which is the wealthiest, most technically advanced and as a result, the noisiest nation in the world, would need to expand and accelerate its current research in the architectural acoustics and noise control one hundred fold to match the Canadian program on a per capita basis.

4 A Proposed Program in Architectural Acoustics

4.1 Basic Problems

From the material outlined in the introduction it is clear that there are a number of acoustical problems of national scope which urgently need attention in order to catch up with public needs and keep pace with the building industries' advances in product technology. Among these are:

4.1.1 Methods of Test and Rating Absorptive Materials

The development of adequate methods of test and rating of acoustical absorbing materials.

4.1.2 Sound Isolating Partitions and Floors

The development of adequate methods of test and rating of noise or sound-isolating wall and partition materials, including floors, and all of these as embodied in integrated assemblies of building structures.

4.1.3 Assemblies of Building Elements

The development of adequate methods of test and rating of assemblies of building elements. (e.g. this inquires into the results achieved when massive partitions are mounted on lightweight floors.)

4.1.4 Structure Borne Sound

Investigation of structure-borne sound as it travels through the building structure, and mechanical vibration in buildings.

4.1.5 Machinery Noise

Investigation of sources of noise in mechanical equipment.

4.1.6 Field vs Laboratory Data Comparison

Carrying out of field investigations to validate laboratory developed methods.

4.1.7 Electro-Mechanical Noise Sources

Investigation of electro-mechanical noise (e.g. fluorescent-light ballasts).

4.1.8 Room Acoustics

Determination of the relationship between physical parameters and the results achieved in concert hall and theatre acoustics.

4.1.9 Subjective Response to Room Noise

Determination of the relationship between room background noise and occupant satisfaction or well being.

4.1.10 Subjective Response to Community Noise

Evaluation of outdoor noise including both background and intruding noises and investigation of environmental acceptability. (This excludes those tasks now being pursued by NASA, FAA and DOT.)

4.2 National and International Standards Activities in Acoustics.

4.2.1 Testing the validity of current and proposed standards in architectural acoustics, including the statistical validity and the reproducibility of results with a multiplicity of architectural units made to the same design and specification by different skilled craftsmen employed from within the building industry in order to develop true performance standards.

Standard test methods currently in use, or in development, are:

1. E90-66T : "Tentative Recommended Practice for Laboratory Measurements of Air-Borne Sound Transmission Loss of Building Partitions" - ASTM, Joint E-6 Sub 3 and C20 Sub 6.

2. C423-66 : Standard Method of Test for Sound Absorption of Acoustical Materials in Reverberation Rooms: - ASTM, C-20.

3. E-336-67T : "Tentative Recommended Practice for Measurement of Air-Borne Sound Insulation in Buildings" - ASTM, Joint E-6 and C-20. (Accepted for publication in 1968 Book of Standards)

4. (In ballot): "Recommended Laboratory Method for Measuring Impact Sound Transmission through Floor-Ceiling Assemblies" - ASTM, Joint E-6 and C-20.

5. ISO R140 : "Field and Laboratory Measurement of Air-Borne and Impact Sound Transmission"

6. ASHRAE Standard 36-62 : "Standard for Measurement of Sound Power Heating, Refrigerating and Air-Conditioning Equipment, Criteria for Testing" - ASHRAE.

7. ASHRAE Standard 36A-63 : "Standard Method of Determining Sound Power Room Air Conditioners and Other Ductless, Through-the-Wall Equipment" - ASHRAE.

8. ASHRAE Standard 36B-63 : "Standard Method of Testing for Rating the Acoustic Performance of Air Control and Terminal Devices and Similar Equipment" - ASHRAE.

9. AMCA Bull. 300 : "Standard Test Code for Sound Rating Air Moving Devices" (Revised April 1965). - AMCA.

10. Standard AD-63 : "Measurement of Room-to-Room Sound Transmission Through Plenum Air Systems" - ADC.

4.2.2 Developing test methods and criteria as a basis for the preparation of adequate standards through appropriate standards organizations.

4.2.3 Coordination of national standards activities with ASTM, USASI, ISO, IEC.

5 Nature and Size of Facilities Needed

5.1 Facility Requirements

It has been unfortunate, in terms of progress, that the space requirements for architectural acoustics research and testing are of necessity large. The spaces are as large as or larger than most of the rooms in which materials are conventionally applied with the exception of an auditorium or concert hall. This permits the study of fundamental properties of spaces and materials and allows the experimental delineation of theoretical conditions dependent on measuring sound in a large volume free of nearby walls or obstruction.

The particular spaces required for architectural acoustics research and testing include the following carefully isolated (vibration and sound) rooms:

(a) Reverberation room, 15,000 ft^3, R

(b) Three side-by-side transmission loss test rooms, one of which is adjacent to R, 7,500 ft^3 each, T_1, T_2, T_3.

(c) One or more floor transmission loss and impact noise test rooms above or below T_1, T_2, T_3, 7,500 ft^3 each. These rooms should not have openings into one another but should have access from a common gallery. Although only one pair of rooms, one above the other, meets the minimum requirement, flexibility and the prospect of a long term program in floor-ceiling research indicates that all three pairs as proposed will be necessary to keep pace with the nation's research needs.

(d) An anechoic room having a volume before installation of the sound absorbing elements of about 50,000 $ft.^3$ It appears desirable that this room be adjacent to the last of the small transmission rooms.

(e) A psychoacoustics laboratory with two rooms separated by a one-way glass panel for use in jury rating, and noise exposure measurement work. The two rooms should have a floor area of about 400 to 500 ft^2 each.

(f) A control room for all of the spaces listed in (a) through (e) above should be provided in close proximity to all the spaces. The control room requires a considerable amount of access by cables from the other rooms, and should have an adequate level of protection from electromagnetic interference from both internal (e.g., the crane) and external (e.g., the substation) sources. EMI and RFI screening may not be required but it should certainly be evaluated since the signals being processed by equipment in the control room will often be at the one microvolt level, and possibly at the 0.1 microvolt level as the state of the art advances.

(g) A scale model laboratory for the study of acoustical models under suitable acoustical environments. The room should be capable of being converted from reverberant to moderately absorbent conditions. Different phases of work over a period of one to two years might require the change, or possibly at more frequent intervals. The floor area required is in the range of 800 to 1000 ft^2.

(h) A sound and vibration measurements laboratory will provide for the testing, calibration, modification and evaluation of acoustical measuring equipment. It will also serve as the source for special measurement facilities not normally required in the control room. Equipment such as stroboscopic light sources, accelerometers having a wide range of sensitivities, high intensity sound generation equipment, and the electronic and acoustical facilities for the model test facility would originate in the sound and vibration laboratory. In this laboratory would also be located test facilities for measurement of damping materials, sealants, and the mechanical behavior of vibration isolating materials and equipment.

(i) A Simulated Field-Test building inside the enclosure of the architectural acoustics facility is recommended. The Simulated Field-Test Facility will permit the complete installation of a three story section of an actual building, for the purpose of evaluating the acoustical behavior of complete assemblies of building elements of which some may be specifically intended for sound isolation. To date almost nothing is known about sound-isolating materials under actual field conditions except that they do not behave in the same way that they do in the laboratory. Although this facility could be located outside of the architectural acoustics enclosure, it would lead to some difficulties in terms of weather protection and delays that might be barely tolerable in commercial construction, but would probably be intolerable in a research program. The Simulated Field-Test Facility will require a floor area of 40' x 50' and a clear height below the crane of 40' and an isolated floor slab probably below grade. It is possible that the first floor would be one story below ground level.

(j) A mobile Field Laboratory in a small truck or van suitably instrumented to make noise, reverberation, and sound transmission measurements in the field. The van would contain battery-operated as well as line-operated equipment, permitting field measurements of noise in very quiet backgrounds.

Figures 1 and 2, attached, are partial plan and elevation sketches of the reverberation, anechoic, and transmission chambers showing desired physical relationship and general construction features.

The reverberation rooms including the large reverberation room and the small rooms associated with the transmission loss facilities are useful in studying the behavior of sound in rooms, the measurement of fundamental physical acoustical properties and in the performance of all of the standards testing now listed or being considered for future adoption in this country and Europe. Even if a future standard were to be adopted in ten or fifteen years that required a room of specific dimensions or shaped or splayed walls, the rooms proposed here would still have to be used to relate what happens in the specially shaped standard test spaces to what happens in the rectangular rooms of the real world.

The possibility that it may be desirable to have some tests with sound originating in the reverberation room and terminating in the anechoic room and vice versa suggests that all five ground level rooms be in line. For example, in the testing of air conditioning elements, a complete run of duct could be contained within the five rooms. This would protect it from outside noise and at the same time provide the appropriate acoustical source and termination conditions.

The reverberation rooms would have suitable openings between appropriate pairs so conventional doors, windows, and typical sizes of building elements including walls up to 15' x 25' could be studied.

5.2 Transmission Room Application

The six recommended rooms of the transmission-loss facilities are paired at one level for side-by-side transmission and vertically for testing floor-ceiling structures for their sound isolation capabilities. The three types of openings in the side-by-side rooms provide for the study of the effects of edge constraints on the sound isolation capabilities of building partitions. These can then be compared to the real-life conditions measured in the field and in the Simulated Field-Test Facility. This has for the last thirty years been one of the gray areas of architectural acoustics and it is today one of the most critical. The relationship of laboratory test data to field results has not been determined. Everything that has been done to date has been on the basis of experience, estimates, and judgment. Actual knowledge is needed to replace those less desirable approaches. Manufacturers continue to issue claims based on laboratory tests, often made in the laboratory that gets them the highest rating, while holding rigorously to the test standard.

A slightly different problem occurs with floor-ceiling tests. Here, many floor construction techniques used in modern buildings are fabricated from poured in place systems. These may include concrete or corrugated sheet metal, inverted concrete pans, and the old beam and slab designs. It is, therefore, necessary to pour concrete in place if a valid test is to be obtained. Under these circumstances it is necessary to wait almost one month for the concrete to be thoroughly cured before conducting a test. In turn only twelve tests could be run in one year on this basis. By providing three openings for floor-ceiling system, openings for wood-drywall construction systems would be available. Under some circumstances two or all three floor-ceiling transmission test openings would be devoted to drywall systems. However, without the option, any complete laboratory would be greatly hindered.

5.3 Application of Facilities to Development of Standards

Just as in metrology where standards of weight, length, voltage, resistance and time form the basis of commercial-quality standards available to industry and the public, in acoustics the measurement of acoustical properties of materials is founded on having precise information about certain physical parameters. In fact the determination of precise values of acoustical properties is dependent on being able to measure accurately the dimensions of the reverberation rooms, the time delays between trigger pulses or zero crossings, the dimensions of a sample and values of voltages generated by electromechanical transducers (in some cases microphones). One valuable feature of the interrelated rooms is the ability to repeat measurements of various types in different rooms to determine the reproducibility of a test. For the U. S. Government this has two fold significance. For an acceptance test standard, it is imperative to know whether differences in the sound absorption of a product or the noise level of another are significant when measurements for qualification are made in one laboratory and measurements for acceptance are made in another. Furthermore, in the development of nationally and internationally accepted standards it is of importance to have standards which produce consistently uniform results when the measurements are made in accordance with the standard. Only through research which can be carried out in the type of facility which is planned here can such determinations be made.

There can be little doubt about the need for having an architectural acoustics testing and research facility. Its produc-

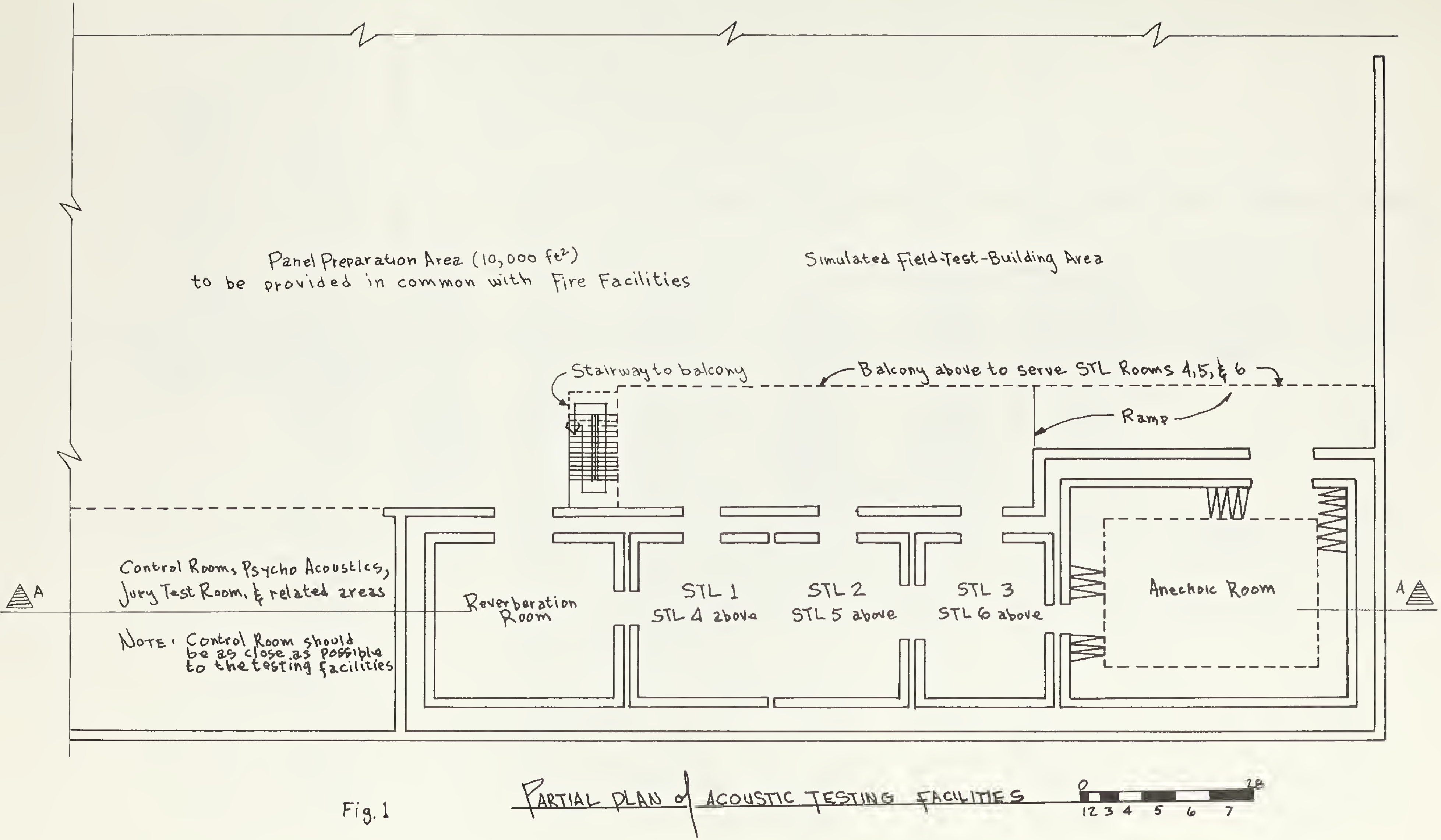

Fig. 1 PARTIAL PLAN of ACOUSTIC TESTING FACILITIES

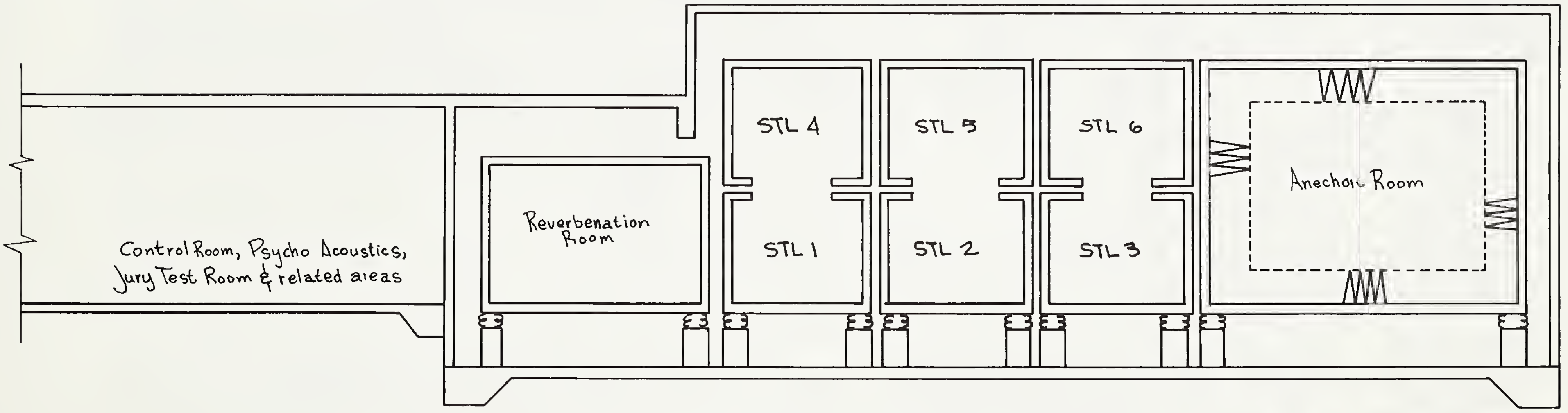

Fig-2. SECTION A-A of ACOUSTIC TESTING FACILITIES tivity in terms of value can be a sizeable percentage of the GNP. The need for a psychoacoustics laboratory within the architectural acoustics testing facilities is critical although possibly not as obvious. However, without it there is no way to relate human response to noise in buildings and the physical properties which one can measure in architectural acoustics tests. In this psychoacoustics laboratory, it will be possible to evaluate the response of small groups of people under both office and recreation situations to noise heard through partitions, air conditioning duct systems, and from the out-of-doors. In the first two instances, actual partitions could be installed between pairs of reverberation rooms, one of which was finished in the form of an office or living space. The last case might make use of tape recorded signals modified to represent their sound after leaking in through windows or walls of typical modern residential and office buildings.

Other tests would be conventional psychoacoustics tests repeated for verification on larger populations or with special conditions applicable only to architectural situations and not envisioned by the experimenter in the original test.

The need for such verification is apparent at the present time. The response of people to noises heard leaking through apartment or hotel walls does not appear to be directly related to the "speech privacy index" or to the speech articulation index. This appears to be due to the fact that the sound is heard at very low levels. However, to date no thorough research has verified or invalidated this. Another critical situation is the need for an understanding of the response of people under real-life situations to low frequency noise. There appear to be some limits to the validity of current criteria for room noise levels. Much of the problem occurs at low frequencies where instrumentation of the past was deficient, where many earlier noise generators were low in output in contrast to today's noisemakers, and where today's building construction provides little sound isolation compared to brick and masonry.

6 Alternative Solutions to National Needs

6.1 Special Laboratories Required

In order to evaluate the existing U. S. facilities for architectural acoustics it is convenient to summarize the various kinds of special laboratory rooms that are required. The following list was developed from Section 5.1 above.

a. Reverberation room
b. Transmission rooms
c. Anechoic room
d. Impact testing room

e. Field test simulation spaces in an actual building
f. Plumbing noise test facilities
g. Machinery noise test facilities
h. Psychoacoustics study space with adjacent observation room
i. Acoustical scale model test facilities
j. Air handling systems and terminations noise test facilities
k. Advisory services in coordinating government and private standards in architectural acoustics
l. International and domestic standardization activities

6.2 Existing Facilities and Their Capabilities

If we now list the active private and commercial acoustical facilities doing any work at all in architectural acoustics we can tabulate the capabilities of these facilities with respect to the research areas tabulated above.

Alternative Ways to meet need or exercise scope:

A. Existing architectural acoustics facilities or laboratories	B. Capabilities											
	a	b	c	d	e	f	g	h	i	j	k	l
Independent Acoustical Laboratories												
1. Riverbank Acoustical Laboratories of I I T R I	a	b		d			g					
2. Geiger & Hamme, Inc.	a	b		d								
3. Kodaras Acoustical Laboratories	a	b		d			g			j		
4. Cedar Knolls Acoustical Laboratories	a	b		d			g		i	j		
Institutions												
5. National Research Council of Canada Div. of Building Research	a	b		d			g				k	l
6. University of California, Los Angeles	a	b	c						i			
7. Illinois Institute of Technology Research Institute, I I T R I	a		c				g		i			
Industrial Acoustical Laboratories												
8. United States Gypsum Company	a				e							
9. National Gypsum Company	a	b		d								
10. Ohio Research Corporation, Donn Products, Inc.	a	b										
11. Conwed Corporation (formerly Wood Conversion Company)	a											
12. York, Borg-Warner	a						g					
13. Armstrong Cork Company	a	b		d								
14. Owens-Corning Fiberglas Corporation	a	b		d			g					

15.	Minnesota Mining and Manufacturing Co.	a
16.	Johns-Manville Research & Engineering Center	a
17.	Vibro-Acoustics Ltd. A Douglas Engineering Company	a b
18.	Many A C Manufacturers	a b

Of 12 capabilities identified in 6.1 as important to basic research or services needed in architectural acoustics, only 6 are presently available in independent commercial or institutional testing organizations in the United States.

Although personnel from each of the listed organizations may attend meetings of domestic standards organizations and may contribute to or vote in international standards organizations, this does not compare to the full scale research programs required to develop and evaluate proposed standards.

6.3 Use of British Facilities

The question has been raised as to whether the United States could make use of the facilities at the Building Research Station in England. There are several strong arguments against such a plan:

(a) The facilities at BRS are not as extensive as those required for the programs outlined above.

(b) The type and nature of the tests performed at BRS are similar but not identical to those proposed. These are standardized currently in the United States but would probably require modification of the BRS instrumentation.

(c) Tests to be conducted on materials of the U. S. manufacture would require the shipment of materials to BRS. The difficulty of obtaining suitably skilled local trades to install such materials may pose serious problems. It is currently a problem at some laboratories in the U. S. now. Also site conferences where the materials are installed in cooperation with a manufacturer or trade association in order to assess progressive changes in method of sealing or support would pose transportation problems for large numbers of persons. It should also be pointed out that common items such as gypsum board and lumber have different sizes and properties in England. Even in the U. S., east coast lumber and gypsum board are produced which have densities and tensile properties slightly but possibly significantly different from those materials produced in the west.

(d) Shipment of completely assembled structures to England is obviously unwise. The problem of shipment up and down the east coast has even been difficult, with some samples arriving badly damaged after traveling the relatively short distance from Virginia to New Jersey.

(e) Limitations on foreign travel by scientists and an unfavorable balance of trade, which are not always predictable, would create difficulties in utilizing foreign laboratories for essential U.S. research programs.

6.4 Use of the NBS Sound Laboratories

The use of the Sound Laboratory, under construction at the NBS Gaithersburg site, for studies in architectural acoustics has been investigated. The only two rooms in the Sound Laboratory that would serve the needs of the architectural acoustics program outlined in Section 4 are the reverberation and anechoic chambers. However, these facilities in the Institute for Basic Standards will be engaged on a full-time basis for the purpose of the determination of fundamental properties of materials, investigation of sound fields, calibration of transducers, and the development of measurement and calibration techniques. It is in this area that there has been considerable fundamental work throughout the United States. However, without the availability of an NBS facility to provide the basic primary standard of measurement to the highest order permitted by the state-of-the-art, the laboratories of this country will have no assurance that their measurements are reliable and there will be no focus of leadership for research on calibration techniques and for the development and maintenance of suitable measurement standards.

6.5 Construction of New NBS Facilities

The final alternative method considered for meeting the need for scientific studies in architectural acoustics was the construction of the facilities described in Section 5.1 at the Gaithersburg site of the NBS.

Further analysis of the various alternatives is provided in the following Sections of this report.

7 Analysis of Alternatives

It is clear from the tabulation in Section 6.2 that there are not adequate facilities in the United States for carrying out the basic program of architectural acoustics research required to meet the national needs outlined above. Furthermore, the building industry, which is characterized by many small businesses, highly fragmented effort, and a dependency on a large number of trades for field assembly of structures, cannot provide a focus of research leadership in a discipline like architectural acoustics where successful design depends on arrangements of elements, workmanship, geometry of spaces, surface characteristics of building elements, and the subjective response of human brings.

7.1 High Cost of Facilities, a Deterrent to Construction

Another reason for the present lack of adequate facilities is the high cost of acquisition of such facilities and the high unit cost for each test. Although many small builders and home owners may wish to have data, there has not been any public or commercial group willing to finance construction of suitable laboratories at a university or existing commercial facility for producing the requisite handbook information. Some existing commercial and academic laboratories do operate in a few of the areas needing attention, but the funding is inadequate in terms of the national needs.

7.2 Privately-Acquired Data Not Fully Available

One important facet of testing is the pressure of sales organizations to suppress unfavorable data even though it might make a significant contribution to the knowledge of acoustics. Such commercial problems do not exist at NBS and the careful use of generic products to develop the principles of acoustic design could occupy the staff for many years to come.

7.3 Private Facilities Have a Limited Scope

As indicated under 7.1 above, the facilities to fully explore the scope and nature of the problem are impractical in terms of the commercial and academic facilities needs, dollars and staffing. Even if all the funding were available to the commercial and academic laboratories, they could not maintain programs at the required level under present concepts of staffing and operating procedures, nor does it appear desirable to change the situation except in terms of having available the cooperative capability of a full-time architectural acoustics research facility with which information exchange systems can be developed.

7.4 Sustained and Coordinated Leadership Required

In view of the facts that long term research is not profitable except as part of the national purpose, and that no private, commercial or academic laboratory has yet undertaken such work in any depth, it is obvious that if the desired benefits are to be achieved, they must be realized through a Federal laboratory.

The only conclusion to which this review leads is that there is no adequate practical alternative to an architectural acoustics research facility in NBS, for the following reasons:

(a) Only NBS is in a position to offer continued leadership and coordination of the major research effort required to yield the urgently needed answers in architectural acoustics and to help promulgate meaningful standards.

(b) There are no existing facilities capable of doing the job.

(c) Industry has not found it profitable to construct or maintain such facilities.

(d) Academic institutions have been unable to finance construction of such facilities and have been unable to maintain continuity of program level for the meager programs that they do maintain.

(e) Unbiased services to the U.S. Government are available from only a few sources, but even these sources are unable to carry out some necessary tests.

(f) The necessity for safeguarding the government's investment in housing rests in part on suitable architectural acoustics standards which can best be developed through independent unbiased research.

8 Contribution of an NBS Architectural Acoustics Facility to Meeting National Needs

The Building Research Division of the National Bureau of Standards, if adequately staffed and equipped, could make an economically and sociologically justifiable contribution to the national needs in the area of architectural acoustics and noise control in several ways:

8.1 Basic Research

Through research, an architectural acoustics facility could provide a basis for development of new standards and methods of testing; new techniques for developing the required noise control and privacy; and could stimulate industry to develop new products where laboratory research indicates that they can be realized or there is an existing need not yet fully seen by industry, thus contributing to the GNP in the long term.

8.2 Applied Engineering

Through applied engineering research, work in the proposed Architectural Acoustics Facility could demonstrate the practical techniques that will result in an improved environment even if it must be carried out on a custom basis for a critical government installation. As part of a continuing program to develop a new enlarged applied technology in the field, the Facility could evaluate the economic feasibility of projects which currently are not being undertaken by industry because the economics of noise control and adequate architectural acoustics design are not clearly understood in the required area.

8.3 Information Clearing House

Another useful function of the Architectural Acoustics Facility in BRD would be to serve as an information center and clearinghouse and as a stimulus to interest industry such as the appliance industry in using state-of-the-art techniques for noise control.

8.4 Development of Information for Standards

The Architectural Acoustics Facility in BRD could bridge the gap between pure physics where much that has been done in theory has yet to be applied, and the current commercial and industrial needs in the areas of standards, test methods for new products, methods of rating, development of techniques for relating human response or acceptance to the physical test result.

8.5 Additional Functions

There are a number of other services which the architectural acoustics group of BRD could also perform on a suitably scheduled basis. These services, if not controlled or scheduled, could consume all of the time of the Architectural Acoustics Facility personnel. However, unless some assignments are carried out in these areas, on a scheduled basis, the personnel will not be able to examine real-life problems, a situation which in itself leads to unrealistic approaches and sterile programs unrelated to actual industry and public needs.

8.5.1 A primary activity of Architectural Acoustics Facility personnel should be the measurement and evaluation of community noise, measurement of the levels of background noise in buildings, measurement of the sound isolation provided by various partitions in actual field installations, and the measurement of noise intrusions in communities and inside actual dwelling spaces. Also the noises made by appliances in actual residential use differs greatly from the noise made in a laboratory, and these noises must be measured and evaluated in terms of the actual situation. This type of work is best performed working from a mobile laboratory, a suitable van or truck equipped with quieted power sources and the electronic and acoustical equipment for carrying out the measurements. Some of the equipment would be permanently installed, while other items such as microphones would be drawn from the supply room for the particular program. Various field programs using the same type and quality of equipment as used in the laboratory situation would permit direct comparison of the field and laboratory results without errors introduced by equipment differences.

8.5.2 Field performance checks to verify laboratory results can be carried out by using the mobile laboratory at a specific site.

Such tests could evaluate the performance of partitions, mufflers, and nominally quiet mechanical equipment in the field. This should not be a routine duty of the Architectural Acoustics Facility personnel, but would be done solely for the information of NBS personnel or on occasion could be done for the purpose of evaluating test methods and obtaining information needed for research studies. Where difficult measuring conditions exist, field performance tests could lead to development of new techniques not now available. NBS had started activities in this direction with respect to acoustical tile materials in the early 1950's, but the work was not completed.

8.5.3 In a similar way Architectural Acoustics Facility personnel could assist other government agencies on the basis of the uniqueness of a specific problem, or in cooperation with outside consultants where the experience of the Facility's personnel would be unparalleled on the outside. However, the Architectural Acoustics Facility's personnel should not be considered as a design service, since, as with testing for conformance, this could easily occupy the entire staff on a full time basis, and no architect would seek private consultants to whom he must pay a fee if the BRD supplied the service without charge to the U. S. Government agency involved, or at nominal cost.

8.5.4 A very important function of the Architectural Acoustics Facility would be in their background information and reference referral services. Every acoustical consultant today answers dozens of questions each month. These arrive by mail and telephone and run the gamut of requests for the name of a product or the best method of quieting a fan, up to requests for detailed source materials on techniques of damping metal structures. Many background questions can be answered in a few minutes usually referring the caller to appropriate information in the literature or in a source of manufacturers listings. The Architectural Acoustics Facilities personnel would be in a competent position to provide thorough unbiased information on the subject.

9 Cost Benefits of NBS Architectural Acoustics Program

An additional return to the U. S. Government from the operation of an architectural acoustic facility in BRD is in the form of direct dollar savings on U. S. Government building construction costs. A secondary result is the increase of the dollar value of the FHA financed mortgages on new construction. These savings and increase in value can be achieved through several avenues:

(a) Elimination of currently used but unsuitable attempts at sound isolation. This includes the use of incorrectly designed lightweight partition systems for which premium prices are paid, the elimination of costly "trick" construction methods in drywall systems in which the "tricks" do not provide the claimed isolation, and the review of special techniques proposed for application to assure that they do not violate good sound isolation techniques.

(b) Institution of recommended practices for achieving adequate sound isolation in government office buildings. Such recommended practices would in no way conflict with the architects freedom to design the buildings and their interiors, but would provide him with the basic elements of good acoustical noise control. This would yield considerable monetary savings by elimination of the remedial noise control work now required on a large number of buildings in which the U. S. Government has an interest of some kind or is a tenant.

(c) In private buildings and hospitals financed through FHA and the Hill-Burton program, the value of the property can be increased through the use of good sound control dictated by minimum property standards or regulations governing construction standards. There is a long list of apartment and office buildings and a shorter one of nursing homes and hospitals which have had occupancy problems from the earliest days of their completion. A large number of apartments designed to conform to the FHA standard do not meet the requirements. Among the reasons are the inadequacy of the current test standards. This in turn is caused by insufficient information on the behavior of materials used in the construction system. Furthermore, design and construction are different phases of the project. An understanding of the system used may lead to improvement of the construction methods to assure that the requirements of the design are met.

(d) Development of qualification standards and methods which will allow architects to "nail down" the acoustical properties of vendors products in advance of bidding so that any product meeting the testing requirements for qualification as an approved item can be used by the contractor. In other words, here is one place where the architect can specify how the "or equal" is to be determined.

10 Construction and Operating Costs

The table below summarizes the facilities costs and personnel required to operate the facility.

ARCHITECTURAL ACOUSTICS FACILITIES

Estimate of Costs

8.1 AE and Construction

8.1.1	Architectural Acoustics Laboratory	$5,500,000
8.1.2	Simulated Field Test Building (inside 1.1)	200,000
8.1.3	Cranage, fork-lifts, jacks	100,000
		$5,800,000

8.2 Other

8.2.1	Instrumentation for 1.1, 1.2	$ 250,000
8.2.2	Tools and shop gear	100,000
8.2.3	Mobile Acoustic Van, with instrumentation	40,000*
		350,000
	TOTAL	$6,150,000

8.3 Operating Cost per year (as of 1969)

8.3.1	For staff of 25 members consisting of:	$ 625,000/yr

5 Physicists
1 Mathematician
5 Acoustical Engineers
1 Psycho-Acoustician
2 Electronic Engineers
1 Architectural Engineer
1 Mechanical Engineer
1 Computer Programmer
5 Laboratory Technicians
1 Draftsman
2 Administrative & Secretarial

8.3.2	Supporting services of carpenters, plumbers, masons, etc.	$ 25,000
8.3.3	Materials, supplies and outside contract services	100,000
	TOTAL ANNUAL OPERATING COST	$ 750,000

*The cost of the mobile acoustic van is not included in the total, because it is scheduled for procurement in advance of the remaining facilities.

11 Facilities Location and Multiple Use of Facilities

The Architectural Acoustics Facility, although it requires similar instrumentation and services to that of the Sound Section in IBS, will not in general be performing tests on similar specimens nor will they require duplicate services. The more closely related specimens used by Fire Research and Climatic Exposure lead to much greater commonality with these facilities. The Architectural Acoustics Facilities must not be too near sources of RF energy or EMI but otherwise can be located near a common specimen preparation area and might share office space, duplicating facilities, specialized design personnel, computer facilities, storage facilities.

12 Conclusions

On the basis of the review of the architectural acoustics needs of the United States and in particular the appropriate program which should be under way at the NBS, and the analysis of the possible means of accomplishing this program, the Subcommittee on Architectural Acoustics concludes:

12.1 There are major needs not now being met in the field of architectural acoustics research and in particular in the development and evaluation of national and international standard methods for testing and evaluating products, systems, and techniques for the control of noise in buildings and for the design of spaces for auditorium and meeting hall use in public buildings.

12.2 There is an urgent need to develop information on which other government and industry groups, sometimes cooperatively with BRD, can base performance criteria in all areas of architectural acoustics and noise control.

12.3 There are not adequate existing facilities for carrying out the urgently needed research at any outside facility in this country or elsewhere.

12.4 The program that would be carried out in the proposed Architectural Acoustic Facility would make possible direct monetary gain to the U. S. Government as well as increased value of government financed or guaranteed private buildings.

12.5 No financially or professionally acceptable alternative to this proposal was found by this study.

APPENDIX A

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Transmission of Sound Through Building Materials. S552
V.L. Chrisler. Sci. Pap. BS 22, 227 (1927)

Soundproofing of Apartment Houses. V.L. Chrisler.
Tech. Pap. BS 21, 255 (1927) T337

Sound Insulation. V.L. Chrisler
ARchitecture 57, 87 (February 1928)

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Arch. Forum 50, 623 (1929) 765 (1929)

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Soundproofing of Airplane Cabins. V.L. Chrisler and W.F. Snyder. BS J. Research 2, 897 (1929) RP63

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Air Commerce Bul. 1, 21 (1930)

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Measurement of Sound Transmission. V.L. Chrisler, J. Acoust. Soc. Am. 1, 175 (1930)

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New Industry - Manufacture of Sound Absorbing Material (August (1932) TNB184

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An Automatic Reverberation Meter for the Measurement of Sound Absorption. W.F. Snyder, Research Paper No. 457, Bureau of Standards, J. Research, Vol. 9, (July 1932) RP457

Measurements with a Reverberation Meter. V.L. Chrisler and W.F. Snyder. J. Soc. Motion Picture Engineers, 18, 479 (1932)

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A Discussion of Some of the Principles of Acoustical Insulation. V.L. Chrisler. (1933) C403

Sound Absorption Coefficients. V.L. Chrisler. J. Acous. Soc. Am. 6, 115 (1934)

Dependence of Sound Absorption Upon Area and Distribution of Absorbent Material. V.L. Chrisler. J. Research NBS 13, 169 (1934) RP700

Acoustical Work of the National Bureau of Standards. V.L. Chrisler. J. Acoust. Soc. Am. 7, 79 (1935)

Recent Sound Transmission Measurements at the National Bureau of Standards. V.L. Chrisler and W.F. Snyder. J. Research NBS 14, 749 (1935) RP800

Architectural Acoustics. P.R. Heyl and V.L. Chrisler (1938) Supersedes C396 C418

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Supplement No. 2 to BMS 17, Albert London (1947) BMS 17

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Sound Absorption of Installed Acoustic Materials. Tech. News Bul. NBS 37, 54 (April 1953) TNB

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Interference Patterns in Reverberant Sound Fields. R.V. Waterhouse. J. Acoust. Soc. Am. 27, 247 (March, 1955)

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CHAPTER 5

FIRE RESEARCH

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Chapter 5

Fire Research

1 Executive Summary

The oft-quoted fire losses in the United States, $1.7 billion property loss and 12,000 lives lost annually, are the highest in the world. No doubt the high standard of living in the United States brings with it many appliances and special fuels which account for this record. However, one may well ask why modern science and technology have not made better progress with the fire prevention problem just as they have done in so many other fields. This question has the simple answer that the United States has never applied modern science and technology to these problems with the same vigor that has been applied in other areas.

The National Bureau of Standards because of its work in the fire area over many years is aware of the needs, and the Fire Research and Safety Act of 1968 shows the recognition in Congress for this problem.

To carry out any part of the required study involves special facilities and this report has been prepared to develop specific needs.

In order to prepare a list of facilities needed for fire research at the National Bureau of Stnadards, the fire problem, as it exists in the United States, has been studied; and a comprehensive program has been devised to meet current deficiencies.

This program is presented in two parts: Fire Research and Engineering, and Fire Safety and Information.

The first of these parts deals with the details of the scientific, technical, systems, and economic parts of fire and fire operations. It begins with special investigations to delineate the fire research problem; it presents the general nature of the work required in ignition, fire spread, toxic products, flammability of materials and the fire performance of building systems. Then the problems of fire detection and fire suppression are considered, followed by a program of required studies in the behavior of people in fires and the operating techniques of fire fighting organizations. Finally, the needs for additional medical research relative to burns and asphyxiation and the needs for special instrumentation are noted.

This part of the program is such that work at the National Bureau of Standards and on contract to a wide variety of other organizations are both necessary for a full application of modern technology to the fire problem.

In the second part of the program an attempt is made to assess the real magnitude of the fire problem and to inform in all aspects of fire science and technology all those who need to know. It begins with the assembly and statistical analysis of the fire losses, continues with an analysis of our common domestic and industrial operations and materials to assess the fire hazard involved, and then considers how to make this information available to the firemen and the general public through educational programs. Special programs will occasionally be necessary to evaluate and demonstrate some new device or technique. Finally, a Fire Science Information Center in the form of a library and information distribution service is contemplated.

It will be obvious to all who work in the fire field that all of these problems already receive extensive attention from many organizations. The work of these groups should not be duplicated nor inhibited in any respect. Their work is highly laudatory and covers their chosen tasks as completely as their financial resources make possible.

Therefore in this second part of the program, the National Bureau of Standards would have a relatively small effort as required to carry out parts of the program in which no group is interested or to properly monitor sponsored work. The National Bureau of Standards would be receptive to any and all proposals from competent groups requesting financial assistance to carry out their chosen tasks better or more completely.

2 Introduction

The fire problem is first and foremost a prevention-type problem. In many areas of fire research, any profit from one's efforts is too far off to make the investment a wise one from an industrial point of view. Non-profit organizations like the National Fire Protection Association and Underwriters Laboratories, Inc., have gone a long way toward filling the need, but there are still major areas where decisions must be made by committee consensus without the benefit of research results which could answer many technical questions with certainty.

The National Bureau of Standards has for many years carried on fire studies which helped to shed some light on fundamental fire phenomena and to supply bits of information to help various volunteer committees arrive at a proper consensus. The Bureau program however, has always been very limited by the funds available. The United States, which leads the world in the application of modern methods to solve most of our technological problems, is notorious abroad in the fire research field for the smallness of our fundamental fire work and the general low caliber of scientific talent brought to bear on this problem.

With the National Bureau of Standards' move to Gaithersburg the already small fire effort received another setback by being moved away from its principal facilities, old though they be. This report was in the first instance intended to recommend what facilities should be built at Gaithersburg to remedy this situation.

However, the Fire Research and Safety Act of 1968, just enacted into law, recognizes the deficiencies in the United States fire work and makes it desirable for the National Bureau of Standards to take a general look at the whole problem before selecting the particular facilities to be acquired.

Before facilities can be intelligently discussed, the research program to be carried out must be examined. This report contains in section 3 "Proposed Activities of the NBS Fire Research and Safety Center" an attempt to lay out the total needs for study of the fire research and safety problem.

This program has not been tailored to any specific budget but has rather been dictated by the fire problem itself and what is now known and done about it. The program as conceived and written does not presuppose that all of the work will be done at the National Bureau of Standards. Quite the contrary, it is expected that the larger part of the work will be carried out by contract with outside groups, either on the basis of well conceived unsolicited proposals made by them or on solicited proposals designed to fill recognized gaps in our knowledge.

Work under this program will not only be carried out outside of the National Bureau of Standards but an occasional piece of work may be financed outside of this country where some especially competent group abroad may make an attractive proposal. This is not a generally recommended procedure, however, because research is more than a series of routine tests, and research done abroad develops the know how abroad. On the other hand, international cooperation in the fire research area is already well established, and the National Bureau of Standards staff should participate in this work to the fullest extent possible as they have done in the past. With a program as recommended, the National Bureau of Standards will be able to play a leadership role in some of these cooperative studies.

In sections 5 and 6 the personnel, facilities, and funding requirements of this program are presented. Of course, the funding level authorized by Congress will vary from year to year and therefore these sections present some discussion of priorities in the research program to assist the National Bureau of Standards to adjust to smaller budgets.

3 Proposed Activities of NBS Fire Research and Safety Center

The National Fire Research and Safety work to be undertaken in-house or to be supported by the NBS Fire Research and Safety Center is presented in the following pages. The program was developed for use in connection with planning estimates for required personnel and facilities. The work is divided into two main sections: Fire Research and Engineering, and Fire Safety and Information.

The first section is devoted to the areas and problems, physical, biological, social, or economic, in which progress in reduction of fire loss or improved safety is hindered by a lack of knowledge.

The second section is devoted to the collection and analysis of data on accidental fires and in the dissemination of knowledge on all phases of the fire problem by in-house or sponsored programs of public education, fireman training or the demonstration of new techniques or tactics. The analysis of fire loss data under the second section will disclose additional research areas, while understanding developed under the first section will lead to new items requiring new demonstrations, training, or education.

The study of unwanted fires involves a large number of disciplines in both physical and social science. All parts of this problem have been recognized at one time or another and with varying emphasis. They have never before, so far as is known, been brought together into a single document designed to disclose what effort is required to reduce the unwanted fire and fire effects to a minimum.

3.1 Fire Research and Engineering

The problems described below require work of many different kinds. The solution of some of these problems requires the use of skills already available or to be acquired at the National Bureau of Standards. Others involve skills elsewhere. The work described would therefore be carried out both in-house and by contract or grant as appropriate.

3.1.1 Problem Indentification - to delineate the fire research problem.

The research program to be undertaken should be one which will have the greatest effect, both long and short term, in decreasing the loss of life and property by fire. Many of the basic fire problems have been recognized and the following program has been devised to assist in their solution. However, many anomalies still exist in fire phenomena and fire behavior which make it clear that there are still important unrecognized variables and effects. General loss statistics, described in a later section on accidental fires, are important but not sufficient. It is necessary to study individual fires in detail and in sufficient number to get specifically needed technical data and to discover previously unrecognized research needs.

3.1.1.1 Fire Behavior Investigation - to discover the major fire phenomena so as to direct the detailed research program toward the essential technical problems.

A statistically significant set of fires, large and small should be studied in detail by special fire investigation teams so as to note and quantify to the extent possible the nature of the fuel burned, construction details, location and process of ignition, rate of spread of the fire on inside and outside surfaces, danger to surrounding structure, effect of openings on ventilation, density of smoke produced, details of fire attack, effect of extinguishment, weather conditions, etc., as related to building construction, building materials, occupancies, etc. Any unusual occurrences should be noted. Each investigating team should include members of the Fire Center staff both to make available the latest technical knowledge and to permit the staff an opportunity to make direct observations of accidental fires.

3.1.1.2 Fire Value Destruction Rate Investigations - to provide the quantitative basis for economic and operational analysis of fires.

In order to determine in a rational way whether or not the budget of a fire department should be increased; more men employed; volunteers replaced by permanent firemen; more fire houses constructed or some closed; more or different equipment purchased; the fire fighting tactics changed, city building codes changed to require less flammable materials; more automatic protection; better detectors; etc.--the rate of destruction of value by fire needs to be known in a more quantitative way for different types of construction, occupancy, fire extinguishment activities, etc. It should be observed that the value of a building in the course of a fire falls rapidly in value by fire, water, and smoke; passes through zero value and attains a considerable negative value; than rises again to near zero value. The negative value is caused by the considerable cost of taking down and removing the remains. Thus at some late point the building should be encouraged to burn out. Much better measures of value are needed before such an advanced technique could be practical. Much of this work could be carried out concurrently with studies under 3.1.1.1 above by adding suitable expert personnel to the investigating team. These studies provide the field data referred to under 3.1.3.1.(a). Much of this work would be done on preplanned fires, although some would be done by an investigating team attached to a large city fire department.

3.1.1.3 Fire Origin Investigations - to assist local authorities with fire cause investigations.

In the course of fire investigations contemplated under 3.1.1.1 and 3.1.1.2 above, technical skills will be developed that are not generally available. These skills would be made available with the approval of the Director of the Center, when requested by a State and/or the local fire marshal. This activity could supplement or when necessary do the work of the local marshal or arson squad by providing for:

(a) Complete Technical Investigations of particular fires;

(b) Technical assistance to a local investigative team;

(c) Specialized laboratory measurements or training. While the National Bureau of Standards has and needs no investigation authority, it should provide on the request of and under the authority of local or state governments the specialized scientific apparatus and services of a BFI (Bureau of Fire Investigation).

3.1.1.4 Pre-fire Surveys - to assess the type and magnitude of the fire hazard by occupancy, climate, personal habits and any other pertinent variables.

The size and behavior of fires which can develop in and among buildings in the absence of fire-fighting forces and equipment are largely influenced by the amount and means of storage of the combustible occupancy or furnishings as well as the nature of construction and placement of buildings. Thus, as a means for technical justification of building code requirements, it is important that techniques be developed, and surveys be conducted, to characterize the ways in which buildings are being occupied and used. It is expected that work of this type will be conducted in cooperation with those concerned with structural loads applied to buildings.

Surveys of a type designed to assess the fire hazards associated with an existing community or portion thereof have previously been conducted by insurance groups. The findings have been used both to encourage the use of more adequate protective procedures as well as to provide a means for establishing insurance rates on property. While insurance rates are of no concern to the Fire Center, the assessment of fire hazard is, particularly as it relates to life safety, and efforts are planned to provide greater capability to measure this hazard by improved techniques. It is expected that much of this work will be conducted cooperatively with or through contract with other interested organizations such as the National Fire Protection Association, insurance organizations, Office of Civil Defense, and/or other groups concerned with classifying fire hazard risks in the field.

3.1.2 Ignition - to develop a quantitative, predictive understanding of a broad range of ignition processes.

There would be no fire without an ignition. Yet in spite of its obvious importance, existing knowledge is confined to qualitative observations except for a few rather simple situations.. And even here work has not progressed to the development of an experimentally verified body of theory which would make quantitative predictions of the observed ignition phenomena possible. It is important to understand the ignition process in greater detail so as to: (1) understand and remove ignition sources, (2) devise a test or tests which measure the critically important ignition properties of flammable materials, (3) select or design materials and/or products for minimum ignition hazard, (4) develop ignition inhibitors, and (5) discover ignition phenomena on which new automatic detectors could be based.

It will be necessary to include the effects of atmospheric conditions as well as materials properties. The studies must include both the ignition of glowing combustion and the ignition of flaming combustion. The development of an adequate understanding of ignition of gaseous, liquid, solid, and mixed phase combustible systems will make possible the development of relevant reference data and prediction processes for practical ignition situations. Most of the research studies undertaken in this section are of the fundamental scientific and engineering kind and will require the close cooperation of theorists and experimentalists for successful work. As always in fundamental work no rigid research schedule is possible because the program will require continual revision in the light of what has already been learned. The following sections 3.1.2.1 through 3.1.2.4 describe briefly problems already recognized but should not inhibit the addition of new ones as needed.

3.1.2.1 Self Heating - to learn the basic nature of those processes which can lead to ignition.

Self heating or spontaneous ignition has in the past been responsible for many costly fires. While the substitution of saturated for unsaturated oils in many domestic and industrial processes has reduced the accident rate significantly, there are numerous aspects of the problem which deserve more attention:

3.1.2.1.1 Biologically stimulated self heating appears still to be a problem in many situations involving agricultural products. Detailed investigations of the process should be supported as required to supplement the present limited understanding of this problem as well as suggest ways for its more effective control.

3.1.2.1.2 Physical processes such as adsorption have apparently been responsible for very large fire losses. Such physical processes may, in some cases, be so exothermic as to offset endothermic reactions or phase changes which normally would prevent continuation of the ignition process. It is important to develop a better basic understanding of the hazards associated with such processes. When this has been achieved, it will be possible to develop engineering data to make predictions of this type of self ignition more useful in preventing these often mysterious fires.

3.1.2.1.3 Chemical reactions of an exothermic nature provide another mechanism for self heating. There are many materials which can react in this way. Some of these may present problems primarily during manufacturing operations, while others evidence a self-ignition hazard in end use of the product. There are other materials which are chemically modified by prolonged aging, at only moderate or normal ambient temperatures, in such a way as to become either shock sensitive or more hazardous from a self ignition viewpoint. A large field exists here, and therefore more work is needed both for fundamental research on the mechanisms involved and for the development of reference data through which engineering predictions may be more accurately made of the hazards involved.

Fundamental chemical studies involving the details of the molecular processes, fundamental thermal constants, quantitative chemical kinetic work, etc., are desirable whenever possible. However, many fuel systems of practical importance are already known to be so complex, as wood or cellulose for example, that there seems to be little hope of any short range return. Therefore, much of the effort in this section must be directed toward the uses for ignition prediction purposes, of intermediate type data such as Thermogravimetric Analysis, Differential Thermal Analysis, Differential Scanning Calorimetry, Combustibility of Decomposition Products, Measured Porosity of Char, etc. In this intermediate area the close interaction between theory and experiment is of top priority.

3.1.2.1.4 The action of inhibitors can be examined in connection with all of the self-heating processes studied above. This study should not only clarify the currently unknown mechanisms of inhibitor action but should also lead to rational ways of discovering new inhibitors or new types of inhibitors which can interfere with the self-heating process. This work should also include studies on the long-term depletion of inhibitors and thus the resensitization of materials supposedly inhibited.

3.1.2.2 Hot Spots - to determine the properties and geometry of fuel systems which permit a potential ignition, a hot spot, to grow into a fire.

A fire results only after a fuel and oxidizer mixture is brought to a sufficiently high temperature. Frequently a fire starts with a mechanical or chemical process which adds energy to a local region within or at the surface of a body of fuel. This may or may not lead to ignition. If the heat generation rate exceeds the loss rate, ignition is likely. Both the fuel reactivity as well as its geometry and thermal properties, especially in the vicinity of the hot spot, will affect the thermal balance. It becomes clear, therefore, that an understanding of the ignition of fuels by hot spots involves consideration of not only the stimulus involved, but the fuel complex and the manner of their association.

The knowledge of the details of the ignition process, both glowing and flaming, will carry over into all consideration of the real meaning of the ignition hazard. It is directly essential in two practical ways; the development of an ignition test for materials which properly simulates the real world ignition conditions, and secondly manufacturers can know with confidence what aspect of their product can be improved in shape, conductivity, surface reflectance, reaction inhibition, etc., to attain safer fire performance.

3.1.2.2.1 Spontaneous Ignition. The self-heating processes studied under 3.1.2.1 above will lead to a fire if conditions are right. When adequately insulated, many materials after lengthy self-heating processes spontaneously ignite. While the initial self heating process for many materials appears to be independent of an oxidizer requirement, for other materials this is not so, nor does it hold for later stages of the ignition and combustion process. In such cases, oxygen by inward diffusion will react at a temperature and composition (oxygen) dependent rate and will lose heat by all mechanisms but mostly by conduction and outward diffusion of product species. Experiments to date have been interpreted by a simple, but inadequate, theory. Experimental studies must include the use of variable porosity as well as variable conductivity of insulation. The theory should probably use more than one reaction as a rate mechanism as well as to quantitatively relate the spontaneous combustion experiment with the results of thermogravimetric analysis, differential thermal analysis, differential scanning calorimeter analysis, and other experiments.

3.1.2.2.2. Hot Particles such as glowing embers from a locomotive or tractor, fire brands from an adjacent fire, welding sparks, or a cigarette can readily serve as an ignition source.

Fundamental laboratory experiments can best be done with a hot wire electrically pulsed since this will provide the best reproducibility and control. While this is well known, the knowledge of what fuel properties are critical, what part fuel geometry plays, the importance of access of air for combustion and convection, is not understood well enough to answer such questions as: how does the texture or construction of a fabric relate to its fire hazard when used as a garment, for what oil properties will welding sparks ignite a small pool of oil on the floor, for what oil properties will welding sparks ignite oily waste, for what shingle properties (age) will a roof be ignited by fire brands from an adjacent building or forest fire? Is it possible to so pack a cigarette that it will go out before it could ignite blankets, paper, or leaves? The firebrand ignition of forest fuels is already under investigation by the U. S. Forest Service and new work should be chosen to complement the work already in progress. Factors causing both flaming and glowing ignition must be studied.

3.1.2.2.3. Electrical sparks either natural, resulting from electrostatic charge exchange, or artificial, as used in internal combustion engine or oil burner ignition systems, may provide either a hazardous or useful means of ignition. Much has been done to define the minimum ignition energies of various gas air mixtures with specific electrodes. More work is needed on the influence of electrode geometry requirements. The fact that electrode geometry has an influence on the ignition casts doubt on the minimum ignition energy idea and suggests that the violent and complex gas motion associated with the spark and the resultant wall cooling of the gas have a significant or even a controlling influence. These factors need detailed study in order to validate or replace the minimum ignition energy idea. While most work has been done with gaseous fuels, there is a real need for research on factors of controlling importance in the ignition of aerosols involving either dispersed liquids or solid fuels.

3.1.2.2.4 Percussion sparks formed during the impact or abrasive rubbing of two materials can be an important source for ignition of flammable gases or dusts. Extensive work has been done on this subject, but more is necessary to properly understand the basic phenomena involved as well as the hazards resulting from use of various materials and fuel geometries. A percussion spark is often a small piece of very hot solid material (metal, stone) which thus becomes the hot spot in the combustible on which it falls. It may be subject to a minimum energy criterion if this idea is validated. On the other hand it is almost certain that some percussion sparks in some materials have catalytic effects which enhance or override the direct thermal effects.

3.1.2.2.5 Friction. The rubbing of solids on each other may cause no sparks but cause a fire by producing a hot spot. Aircraft engine fires, lumber mill fires, machinery fires, and the boy scout fire are sometimes produced by rubbing friction. It is not clear whether this is or is not a special case of one or several of the above items. The details of surface properties of solids as related to lubrication, frictional energy dissipation, abrasion, local heating, etc., are so complex that our knowledge of the subject is fragmentary in spite of extensive studies over many years. Except where the fire group at the National Bureau of Standards or some other group has specific fire-related ideas to develop (theory or experiment), the field is best followed through the rapidly growing literature.

3.1.2.3 Radiant Heat - to develop criteria by which ignition occurs.

Because of the fire hazards associated with the atomic and nuclear weapons, a very large amount of research has recently been conducted on material ignition by short pulses of high irradiance thermal energy. While some important gaps exist in our understanding of this type of ignition problem, the work accomplished has yielded a significant understanding of it. However the more common problem of radiant ignition from low irradiance levels, where conduction and convection cooling become increasingly important, is not adequately understood.

Work is needed to provide a basic understanding of the complex ignition process through which engineering data can be developed to permit rational design where radiant ignition problems are of importance. Areas requiring more attention include:

3.1.2.3.1 Reciprocity failure between critical irradiance for ignition and exposure time will be sensitive to conduction and convection cooling of the heated surface. While some work on this problem has recently been done, much more is needed before real understanding of ignition under low irradiance levels can be developed. Investigations should include not only variable irradiance, but the influence of variations in convection and conduction losses from the heated surface as well as fuel properties.

3.1.2.3.2 Target area, geometry, and surface emissivity and absorptivity will have an important influence on ignition and should be systematically explored.

3.1.2.3.3 Analysis of empirical fire irradiance levels with supporting data, obtained during field fire investigations, will be conducted with the objective of providing engineering data as a base for fire hazard analysis. The measurements need to be made for free flames and for radiation through openings (windows or openings formed by collapsed walls) from actual fires.

3.1.2.3.4 Model studies of radiation sources and ignition by radiation will be necessary in order to make radiant ignition under laboratory conditions similar to that which occurs in the field. Laboratory simulation is highly desirable because of the relative ease, precision, and economy of laboratory vs. field work, and is absolutely essential if a suitable test for the ignition of materials is to be developed.

3.1.2.3.5 The radiative surface properties of materials should be measured in a systematic data acquistion program for a suitable range of temperatures, surface roughnesses, fire decomposition conditions.

3.1.2.4 Convection Ignition - to develop the criteria by which ignition can be caused by convected heat and gases.

Ignition of materials by convective heat transfer is a common and often useful phenomenon. However, understanding of the subject is still very far from adequate. At present, it is impossible to technically define the conditions under which a flame of specified size and temperature will or, more importantly, will just not ignite a fuel of known material and geometry. While an experiment can readily settle the question in any particular instance, it is evident that our understanding of just what to do to achieve safety is at best very tenuous unless the decision is made to go all the way and eliminate either the pilot flame or the fuel. In many cases this may not be possible. It is important therefore to develop a basic understanding of the problem. Areas where work seems important include:

(a) Heat transfer between a flame or other hot product gases from a fire, and a specimen as influenced by size, geometry, specimen reactivity, etc.

(b) Heat generation within a specimen and heat losses from it to the surroundings.

(c) Chemical Inhibitors. Ways in which exothermic reactions by the specimen can be modified or reduced as by the use of chemical inhibitors.

3.1.2.5 Ignition Prediction - to develop and make generally available a computer program for ignition.

The development of a real understanding of the ignition process will make possible the development of a computer program by which ignition can be predicted from a few measured basic material and product properties. Such prediction methods can be useful in designing materials and things for decreased ignition hazard, as well as for advanced fire fighting techniques in which the danger of ignition of adjacent buildings could be continuously computed from the measured radiation levels from an actual fire, etc.

3.1.2.6 Development of an Ignition Rating Test - to give an absolute rating to the ignition hazard of materials and products as used.

At the conclusion of the above work it will be possible to develop that test or tests which will rate the ignition hazard of materials, or products made of them, under various storage and use conditions according to their essential ignition properties and under exactly specified and understood simulated conditions. The importance of such tests is so great that it will be necessary to develop a series of interim tests which can be used prior to the time of a full understanding of ignition.

3.1.3 Fire Growth and Spread - to develop a quantitative, predictive understanding of the growth and spread of a fire.

Once an ignition process has been completed it becomes important to have the capability of predicting the probable growth and spread of the fire through the fuel in which it started and to adjacent fuels. Many properties of the materials are involved; thermal conductivity, specific heat, heat of reaction, pyrolysis, porosity, reaction rate, surface reflectance, moisture, etc. There are many fire produced factors such as convection of burning gases, intensity of radiation. In addition there are many ambient factors such as geometry, ventilation, moisture, etc. However, the present understanding of the fire spread process is so elementary that it is impossible to define flammability of a material except by test in the actual full scale condition in which it is used. It is also improbable that a fire research program conceived now will be effective without major modification as the work progresses. Extensive interrelated empirical and theoretical studies on both full scale and model fires will be required on fire growth and spread under a wide range of fuel property, fuel geometry and ventilation conditions.

3.1.3.1 Controlled burn experiments - to learn in a quantitative manner what real fires do.

Studies of fire behavior will be required in full-size buildings both in special purpose structures on the grounds at NBS and in other non-NBS buildings intended for such studies or made available for this use prior to demolition. Such studies may be conducted in cooperation with activities of other groups such as universities, other government agencies, or fire departments. Typical variables which will be studied include:

(a) Smoke development and movement.
(b) Fire temperatures and radiation. Distribution in enclosures and in structural members.
(c) Influence of building construction on fire growth and spread.
(d) Material properties affecting ignition, fire growth and safety. Effect of geometric distribution interactions.
(e) Fire convection, distribution in enclosure and through openings.
(f) Quantitative evaluation of all fire parameters to correlate with fires in model structures.
(g) Development of model laws and model testing when possible.
(h) Gas movements through exterior openings - facade and upper story fire spread.
(i) Radiation flux from openings - effect on ignition and fire spread over adjacent structures.
(j) Development of "safe separation" criteria needed for building separation and city planning.

(k) Development of a proper fire severity specification by verification, revision or replacement of the present time-temperature curve.

3.1.3.2 Fire Spread Theories - to test the validity of the concepts and hunches on how a fire spreads and to provide the basis for fire spread prediction.

Develop fire spread theories of a wide variety and on the basis of these try to measure real fire spread to discriminate between the possible mechanisms. Correlate fire spread mechanisms, liquid fuels, gaseous fuels, forest fuels, connected enclosure, as well as connected or non-attached buildings.

3.1.3.3 Fire Spread Model Tests - to verify and quantify the relationships between the dimensionless fire spread and the controlling independent variables.

As the basic mechanisms become better understood the strengths and weaknesses of model fire studies will become known. Special attention will be given to those conditions of air movement, temperature and radiation level shown to be important in building fires in the study 3.1.1.2 above. Since any flammability test is a model which is presumed to simulate the full scale building fire, these model studies are essential before a final form of flammability test can be selected with assurance. (see 3.1.3.7 below)

3.1.3.4 Fire Spread Between Enclosures - to develop criteria for the spread of fire from an involved complex.

It has become popular to study fire spread from a room through a door and down a corridor. Such tests are essential but so are tests of fire spread through wall spaces, ventilation and/or plumbing ducts, up a facade. The necessary fire science of heat and mass transfer, convection and radiation, and ventilation, will be studied both model and full size.

3.1.3.5 Radiant Characteristics of Developing Fires - to determine the role played by radiation during fire growth and spread.

Study the process of radiation production during the active spreading phase of fire. This is needed both for its contribution to the heat feedback and fire - fire interaction mechanism so essential to fire growth, and in support of studied of ignition of fuels by radiation and hence fire spread between enclosures and between buildings.

3.1.3.6 Reaction Rate Determining Process During Fire Spread - to determine what actually controls the heat release rate in a fire.

Because of the rapid combustion process in a spreading fire, the reaction controlling step is probably different from that studied under ignition. (3.1.2.1.3). When possible, it is essential to carry this study back to the basic chemical events. However under many circumstances, physical processes are actually in control and criteria are needed to determine when and how. Even when chemical processes may be in control, the essential complexity of the steps may perhaps make a macroscopic approach necessary, via thermo-gravimetric analysis, differential thermal analysis, etc.

3.1.3.7 Flammability Test - to devise a practical test or tests to rate building, clothing and other materials.

After significant parameters of fire spread have become known and the significant ambient conditions for fire spread in an enclosure are clarified, the development of a quantitative surface flammability test method of known applicability will be possible. Because of the immediate importance of this work, flammability test devices of all the kinds now used in various countries should be built (or purchased) and carefully instrumented tests performed on them. This will help to clarify what aspects of flammability each one actually measures and will assist in the development of an interim standard test until the real meaning of flammability becomes known.

3.1.3.8 Negative Fire Spread - to determine the fundamental effects of extinguishing agents on the fire spread mechanism.

The useful processes of extinguishment imply a check in the rate of spread, pending the ultimate fire extinguishment by cooling. Study effect of moisture, steam, atmosphere, vitiated air, combustion gases, CO_2 and other extinguishing agents on the rate of spread of fire over combustible surfaces.

3.1.3.9 Fire Spread Inhibition - to determine the effect of inhibiting agents on the fire spread mechanism.

Determine how the various known inhibitors interfere with the important fire spread factors studied above. Develop new inhibitors to interfere more effectively with the same or other fire spread factors.

3.1.3.10 Effect of smoke production on fire spread - to determine the manner in which smoke may inhibit or enhance fire spread.

The production of smoke is evidence of partial combustion, partial heat release. A smoking fire spreads at a different rate (presumably slower) than a non-smoking fire. The smoke filled gas may have a very low oxygen content and will prevent other fuel from igniting and burning. On the other hand, smoke and other combustible products of partial combustion can produce with air a highly flammable, sometimes explosive, gas mixture which upon ignition can spread fire rapidly and/or cause direct blast damage. Both full scale and model tests of these phenomena will be useful.

3.1.3.11 Rate of Destruction of Property Value - to develop the economic data appropriate to the destruction of property values by fire.

In order to evaluate fire hazards, fire department operations, fire fighting tactics, fire fighting equipment, the rate of value destruction by fire, at the various stages of the fire both with and without various possible extinguishment activities, is needed. Since water and other extinguishment damage may be a large part of the total property damage, special attention must be paid to value loss from these causes. Furthermore when a fire has progressed to the point that major expenses are involved in demolition and removal of debris, the real value may be much smaller than the replacement cost of what has not been burned. For some period the net worth is negative. A wide range of attack tactics covering the full range of possible approaches must be included in the study so as to determine the possibility of significantly decreased losses through modified use of present equipment or through modification of the equipment. These studies involve two essential parts:

3.1.3.11.1 Field Investigations as described under 3.1.1.2.

3.1.3.11.2 A few structures (fire proof) must be built at a suitable field station and the linings and furnishings burned repeatedly to establish significance and reproducibility, and to determine quantitatively the effect of extinguishment operations. Such test fires must, when appropriate, attempt to reproduce any peculiar effects discovered under 3.1.3.11.1.

3.1.4 Combustion Products - Life Safety - to determine the production and distribution of smoke and its relation to escape.

The technical study of combustion products as related to life safety during fires is an area of increasing importance as new and retardant-treated plastic and other materials are introduced for commercial use. In spite of its importance for life safety, considerations of this aspect of the fire problem seem only recently to have been attracting serious attention from regulatory officials. There is much work to be done on this subject before useful engineering methods appear likely to be available for proper application for control purposes.

3.1.4.1 Physical Characterization of Smoke - to develop an understanding of the physical properties of smoke and the relation of these to smoke production, movement, obscuration, and detection.

The NBS has recently announced the development of a quantitative method for measurement of relative smoke production of materials. However, this work made clear the fact that the type of thermal exposure or combustion process used strongly influenced the character of the smoke produced. These and other findings suggest that research studies should include:

3.1.4.1.1 Physical Properties

Devise methods of measurement, as functions of the fuel and fire conditions, of the properties of smoke such as particle size distribution, color, particle density, flame propagation, explosion limits, obscuration, ionization, infrared and radio wave transparencies, sound speed, sound dispersion, and sound transparency. These basic data are fundamental to the ability of the fire to spread explosively as for example when a fireman opens the door and lets in fresh air, the ability of the building occupants to see and use an exit, to the possibility of an infrared (IR), microwave, or echo location or seeing device, and to the possibility of an IR fire locator or a microwave fire intensity meter.

3.1.4.1.2 Physical Phenomena

Further explore basic phenomena associated with smoke production, dispersion, agglomeration, and dropout, important in relating smoke measurement to obscuration hazard during fires and the effect on methods of detection.

3.1.4.1.3 Fire Exposure Conditions

Better define the fire exposure conditions, to which a specimen is subjected, most useful for comparing smoke production of materials as used in buildings or other living quarters.

3.1.4.1.4 Smoke Obscuration

Cooperatively with those active in field investigations, explore ways of reducing smoke obscuration conditions under actual fire conditions. By this means provide a technical basis for those who may find it necessary to establish safety standards.

3.1.4.1.5 Smoke Movement

The smoke produced by a fire produces obscuration and toxic effects not only for the occupant of the room in which the fire starts but variously throughout the building by thermal convection currents, natural drafts (as from wind) and the ventilating system. Determine these movements by correlation of experimental data from full scale and model tests and devise a theoretical treatment by use of a computer where necessary to predict smoke density and composition as dependent upon time in a simple enclosure, a more complex building and a building with a ventilation system and automatic fire detectors with various response characteristics. Through use of such understanding, show ways of devising building construction and ventilating equipment operating techniques to reduce the physical and toxic hazards of smoke during building fires. (see section 3.1.6.3.4)

3.1.4.2 Chemical Characterization of Smoke - to determine the chemical composition of smoke as a function of fuel and burning conditions and as related to toxicity and reactivity.

More people are reportedly killed by smoke and associated hot and noxious gases than by direct flame contact. Furthermore many new products containing high polymeric materials are being used. It is important to know the chemical nature of the decomposition products produced when each of these useful materials is heated and/or burned. Present methods of chemical analysis, while accurate and sensitive, are slow and tedious. Thus there are three major problem areas needing attention:

(a) A systematic program to determine the chemical composition of smoke from various important materials now being extensively used by the public. These analytical studies will be performed by use of available chemical methods in spite of their tedium.

(b) An investigation of the relative permanence of the smoke products, their decay rate and mechanisms of their dispersal or removal from the gas phase. This work should include investigations of the extent to which the compounds in question are adsorbed on furniture and other surfaces.

(c) A research program directed toward the solution of the problems of the analytical chemist. This should include the development of new analytical chemical laboratory techniques, new rapid chemical methods for field use, and new physical type instruments for laboratory and/or field use. These later will occasionally be able to serve as the basis for new automatic detection devices.

3.1.4.3 Modification of Combustion Products - to discover smoke inhibitors.

Inhibitors may exist which can eliminate or greatly reduce the production of smoke. The use of inhibiting agents for modifying the flammability of plastic and other materials has tended to result in combustion products of greater toxic potential. It appears desirable that the Fire Research Center stimulate research towards treatments yielding less noxious decomposition products while at the same time achieving other desired ends. Such work is expected to be done primarily through contract with other organizations, but not those directly concerned with production of the products involved, in order that all results be equally available to all producers.

3.1.4.4 After Fire Clean Up - to decrease smoke damage and reduce the cost of rehabilitation of a fire damaged building.

Little has been done to explore ways in which buildings or other structures can be cleaned of smoke, odors, and organic deposits after a fire. It is in the interest of the public, including insurance organizations, that studies leading to improved methods of this sort be developed. Such work should be supported in such a way that the findings are made available to the public at large.

3.1.5 Fire Characterization of Materials - to provide the basic data for a fire properties handbook and to devise a materials fire hazard rating assessment method.

There are many properties of materials which are influential in controlling the reactions of them or of systems containing them when exposed to fire. While engineering handbooks provide information on many of these properties, the data available have seldom been obtained in a manner to make them directly useful for characterizing material behavior when exposed to fire. In some instances no reliable measurement methods are currently available. In other cases, the properties of concern are only available for an unacceptably narrow range of temperatures or other experimental variables. It is considered necessary, therefore, to support studies to develop engineering information on material properties important in controlling their behavior when exposed to fire. Some of these which should be investigated, to permit predictive calculations or estimates in a systematic way, include:

3.1.5.1 Potential heat content of materials.

3.1.5.2 Heat release rate as a function of fire exposure.

3.1.5.3 Thermo-gravimetric behavior of materials.

3.1.5.4 Temperature-dependent coefficient of thermal expansion.

3.1.5.5 Temperature-dependent thermal conductivity, and thermal diffusivity.

3.1.5.6 Temperature-dependent enthalpy.

3.1.5.7 Temperature-dependent elastic moduli.

3.1.5.8 Temperature-dependent creep and strength.

3.1.5.9 Equilibrium moisture content of materials including hysteresis ranges.

3.1.5.10 Amount, composition, combustibility and explosion limits of gaseous products.

3.1.5.11 Flame spread rate under fire conditions, effect of ambient radiation, etc.

3.1.5.12 Change of phase effects.

3.1.5.13 Spalling - effect of sudden heating or cooling investigated from both moisture diffusion and thermal stress aspects.

3.1.5.14 Reaction with water and other extinguishing agents, devise new tests suitable for material selection.

3.1.5.15 Radiation properties of solids, gases, and liquids.

3.1.5.16 Conditions for smoldering combustion.

3.1.5.17 Porosity.

3.1.5.18 Diffusion coefficients for water vapor and other gases.

On the basis of all the above and the available knowledge of modeling laws, devise a test or rationale from which the fire safety of the material can be determined. A single (yes - no) decision must be made on each material for each proposed use. While it is desirable to have a single test available to make this decision, often it may not be possible to do so. Under such conditions, devise an assessment method which by use of the minimum number of tests yields a useful basis for hazard determination.

3.1.6 Fire and Building Systems - to determine, predict, and improve the performance of the building systems under fire conditions.

For present purposes, building systems include all building parts and functions with special attention to: (1) the structure, (2) escape routes, (3) ventilation, (4) sprinkler systems, (5) detection and alarm systems, (6) domestic water system, (7) waste disposal systems, (8) lighting and electrical system and appliances, (9) heating and cooling systems (fuel, furnace, chimney, airconditioner, distribution system, controls, (10) communication system (telephone or others), (11) comfort (furniture, acoustic finishes, rugs, etc.) (12) beauty (pictures, false ceilings, etc.)

It should be observed, however, that the building as a whole is a complete system and the above implied separation of parts is only valid if the interactions (sometimes large) between the parts are given due consideration.

The general requirements imposed by the accidental fire on building components can be broken into three parts.

I. Safety of occupants. The performance of the detection and alarm system must be so reliable that after years of idleness it will, within 30 seconds locate an ignition and sound an alarm but at the same time ignore many closely similar stimuli as false. The escape routes from every room and from the building must remain open for a suitable period of time after a fire starts. The required time depends upon the size and use of the building and the number and location of the occupants. The ventilation system must not spread toxic gases or fire and must maintain a sufficient level of fresh air and visibility on the escape routes. All building systems must produce under fire conditions the minimum possible hazard to the occupants.

II. Safety of outsiders. The structure must not collapse into the street or onto a neighboring building. It must have sufficiently predictable collapse properties that firemen's lives are not endangered unnecessarily. The building during the fire must not produce radiation, fire brands, toxic or corrosive products, smoke, etc., in hazardous quantity.

III. The preservation of value. All building systems should be of such design and be made of such materials that they ignite with difficulty, spread fire at the slowest possible rate, produce the miminum possible soot and other destructive products. They should be affected as little as possible by deteriorating effects of extinguishing agents (mostly water). The fire protection system must detect a fire and respond quickly and correctly and put the fire out with the minimum of extinguishment (water) damage.

To satisfy all of these requirements, the research program would have to cover nearly the whole of fire research in its broadest sense: the combustibility of materials, their geometric relationship to fire spread, their production of gaseous products; questions of fire initiation, growth, direction and control. These are analysed in other sections of this report. In this section of Fire and Building Systems only the effects of fire on the intended functioning of the above listed building systems are studied.

3.1.6.1 <u>The Structure</u> - to determine the period of time in a fire during which the building structure will carry its design load without collapse or excessive deflection.

Since exhaustive fire testing of every type of building structure in the course of its construction is impractical, the fire structural performance of buildings as built must be predicted on the basis of suitable test results on components. This means that fire performance must be predicted by the building design engineer just as he now predicts the strength and deflection performance of the design under normal use. This latter design prediction starts with test data on small steel specimens or standard concrete test cylinders from which he can compute the performance of the structure to the extent that the building loads and complex structural interactions are known. At present and for normal use, adequate understanding exists for the design of all structural components under simple loading and support conditions. The complex joint interactions can then be adequately taken into account in many cases but even today buildings occasionally collapse because designers fail to do so in relatively simple interaction cases.

The complexity of the structural problem is much greater when it is combined with the thermal problems imposed by fire. Not only do thermal effects produce thermal stresses through thermal expansion but also cause time dependent deterioration of insulating and structural materials. Thus it will be a long time before properties tests on small materials specimens can be made and used as the structural engineer now uses test results from standard tensile and compression tests. In fact it is by no means certain that design starting with fundamental properties data will ever be practical for material of the internal complexity of concrete or wood. If materials properties tests are not a practical starting point, the next smallest practical test unit is the building component. Such tests must specify accurately not only the construction details, but must also specify fires, loading, and interaction conditions. In order to select the right external conditions, separate research is needed on probable fire conditions, probable loading, and a detailed knowledge of the interactions to be encountered in common building design. The fire conditions are now specified by a time-temperature curve. This provides a workable specification of the fire effect pending validation, improvement, or replacement as dictated by the fire research. The loading conditions are in major part the same as for normal use but may be modified during fires by the accumulation of water or deflection or collapse of adjacent structural members. The structural design under normal conditions selects components to carry simply defined dead and live loads and includes the complex interactions between components in ways (generally simplified) which present knowledge permits. Under fire conditions present design does no more than select a form of construction which passed a standard test of some kind. This provides a working method of questionable accuracy. To improve the approach to fire structural design requires the ability to compute the performance of structural members and their fire protection coverings under arbitrarily specified thermal, load, and support conditions starting with the data from some simple, limited test results (properties, components, subassemblies) and that the interaction between units (whatever they be) be predictable for buildings as built.

To date the fire performance of the structure, even of simple structural components, has not been adequately predicted. Such prediction should now be possible for bare steel members but is much more difficult for protected steel, concrete, or wood. Fire tests are necessarily model tests and can only be interpreted when the model laws are known. The present lack of reproducibility of structural fire tests because of undefined constraint conditions can be removed by the selection of some simple constraint specification. However the resultant performance data could be used in building design only if the model laws for component performance are known by direct development from test and/or by theory using measured materials properties and if the actual, effective constraints encountered in a real fire in a real building are known by direct development from typical subassembly fire tests and/or by theory.

The enforcement machinery through the use of building codes is effective in accomplishing the desired building structural integrity in fire only to the extent that their specification assures the correct prediction of the fire performance of the city's building structures. Thus the codes are effective only to the extent of the available predictive accuracy.

The structural research program required to solve these problems should include the following:

3.1.6.1.1 <u>Measure with sufficient precision the stress and strains in buildings as built.</u> This is the basic civil engineering structural problem and is already adequately solved for most normal structural elements or members. Steel, reinforced concrete, and wood structures are included. This study, of course, includes the interaction between all members of the entire building structure. It must answer the question of whether or not the joint-imposed interrelations are so large that the structural system cannot be treated for design purposes as a collection of interacting components but must instead be treated in some more complex way. Considerable component, connected component, and subassembly work will be required on condemned buildings and on full size fire test specimens built for the purpose.

3.1.6.1.2 <u>Measure with sufficient precision the stresses and strains in buildings during a fire.</u> The thermal expansion alters the original stress patterns and greatly changes the stress levels in some locations. The deflections during a fire, even though short of collapse, may be so great as to disrupt other building services. As an example, the breaking of sprinkler system piping may permit the fire to run away. Some of these tests will be carried out in condemned buildings.

3.1.6.1.3 <u>Determine independent variables for fire stresses and develop model laws.</u> This work must include the analytical prediction of fire test results where possible. It would appear that the fire performance of bare steel structures should be predictable at the present time from elastic and thermal properties of steel measured on standard test specimens at elevated temperatures. The required computer program should be written and tested. For wood, available charring rate data should make rough prediction possible but would also disclose the need for other necessary basic data on wood. Reinforced concrete is probably too poorly understood at present in its chemical, internal structural and property changes to make useful prediction possible but analytical studies would clarify the nature of tests needed to develop the model laws. This work must be done at several levels of complexity. The simplest situations should be treated first and can presumably be done with present knowledge. As the structure becomes more complex (as by laying a concrete floor slab on top of a bare steel beam, or by putting an insulating layer on a beam) the problems become more difficult and the attempt to develop model laws by experiment and/or theory will probably disclose new problems which require modifications of the research program.

3.1.6.1.4 Basic study of cracking, spalling, and other failure modes. Much work in this area can be done with laboratory models with electric heating. Some check fire tests are needed to determine the effect of fire gases. The same failure modes need to be studied with surface cooling (by extinguishment) of fire heated members.

3.1.6.1.5 Study of the control of the structural thermal environment by the use of fire protection coverings such as

(a) Layers of insulation

(b) Intumescent paint

(c) The thermal performance of the insulation and the structural member itself should be adequately predictable from known heat transfer laws and should be so predicted. The problems of thermal degradation of the insulation and the failure of adhesion are both more difficult and will require extensive basic studies.

These studies must include the heat capacity of the structural members and the insulation as well as their thermal conductivity. The pertinent property is in fact the thermal diffusivity. Structural members subjected to study must be of all pertinent kinds in all pertinent locations. Beams under a floor on which there is a fire must be considered as well as beams on the ceiling of the fire enclosure. Columns outside of the main wall of a building must be considered as well as those inside. Non-load bearing wall panels must be studied for their fire barrier effectiveness as well as load bearing wall panels for their ability to carry the load. See 3.1.6.2 below.

3.1.6.1.6 Study building component fire test procedures on a continuous basis so as to make available for immediate practical use the best of what is learned in the structural research program. Special attention must be given to the problem of restraint raised by presently used test methods. Even non-load bearing walls may be under load when heated in a fire and restrained by the surrounding building. Regardless of the ultimate disposal of this problem, interim solutions are essential immediately.

3.1.6.1.7 Devise and continually update practical computer programs for the prediction of the fire performance of buildings using the current best test results. At present this could only be done for simple structures of simple materials but the research program should add valid predictive schemes for complex and composite materials as research progress is made. This work is essential on a limited basis as a check on what has really been learned in the research program and thus to expose remaining areas of ignorance. NBS should take leadership in developing a computer structural design program to inform the engineering public of its possibility, potentialities and limitations.

3.1.6.1.8 Study building panels as thermal barriers. Many building panels, whether or not they carry a structural load, serve their most important fire protection purpose by blocking the spread of the fire from one side to the other. This means not only no collapse, and no bad cracking but also low heat transfer. The study of heat transfer through various composite panels should be directed toward the development of computer programs to predict the unexposed side temperature and heat flux from the available or routinely obtainable thermal constraints. Data obtained under 3.1.6.1.5 above will be needed.

3.1.6.1.9 Develop a flexible, modular design of a fire structural test furnace. All present fire test furnaces were designed to commercially fire test structures or to examine in a narrow sense these test methods. The above structural test program is designed to examine the whole of the effect of fire on structures including as a special case current test methods. The furnace requirements will vary with the program. Sometimes very precisely controlled, uniform temperature conditions will be necessary to simulate a new standard test furnace. At other times, it will be required to test a complex building connection with special loading magnitudes and directions while heating by a time and space non-uniform simulated fire. Some form of modular design of (say 3' x 3' x 3' units of fire brick, burner blocks, flue blocks, instrument part blocks, normal and shear load blocks, movement load blocks, etc., should be devised to permit the repeated assembly and disassembly of large, small, and queer shaped furnaces as required by the research program. Some modules should perhaps include some electric heating units so that small model tests could be carried out with this more controllable, and clean, heating system.

3.1.6.2 Escape Routes - to determine the building specifications which will optimize the safe removal of occupants in a fire emergency.

The safe removal of occupants involves many aspects: detection, alarm, existing escape routes, knowledge by occupants of the escape routes, knowledge of location of fire, ventilation of escape routes, panic of occupants, etc. Most of these topics will receive special attention in later sections. In this section only the operational aspects of escape will be considered.

3.1.6.2.1 Collect and analyze statistics on fires in occupied buildings - especially those containing a large number of people. This will require a field (ad hoc) team to study in great detail a few fires. Cases where tragedies occurred and cases where all went well need to be included so as to determine in a statistically significant way what the good and bad practices are.

3.1.6.2.2 As the number, size, complexity, and direction signs of the escape routes change there is a change in the time required for occupant egress and a change in the possibility of panic. If the data under the above proves to be adequate, an operational analysis of the escape operation might aid in optimizing building escape route specifications. Until studies under the above show promise, the escape process cannot be quantified and nothing better than the present educated guess is possible.

3.1.6.2.3 Examine possible new approaches to the emergency exit of occupants from buildings. Can buildings for the aged and infirm have a separate fire exit from every room? Should they be built on one floor giving immediate outside access through a door automatically opened?

3.1.6.3 Ventilation - to determine building ventilation requirements to assure the safety of the occupants and non-spread of the fire.

In spite of the research done on other parts of this program, building materials will continue to emit large volumes of soot and toxic gases during fire conditions. Under fire conditions the ventilating system should continue to function until all occupants are safe. It should be coupled with fire detectors in such a way that all escape routes are free of excesses of toxic gases or smoke to obscure vision until all occupants are out. It should close appropriate dampers to check fire and smoke spread. It should provide for the venting of fire involved areas. It should provide for the emergency installation of wall or roof vents if needed for fire fighting or rescue. Research to be undertaken should include:

3.1.6.3.1 Develop (or use available) computer programs for the calculation of the performance of a building ventilating system under normal and fire conditions. This would include rate of movement of air throughout the building, pressure distribution throughout the building, volume of air intake and exhaust.

3.1.6.3.2 Measure performance details for several buildings and building modifications (open or close various doors and windows) in order to verify the performance predicted by the computer program devised under the above.

3.1.6.3.3 Measure the fire-induced air movements and pressure fields. The time variation of the volume, temperature and composition of the fire produced gases as determined by other parts of the Fire Research Program, will by natural convection modify the operation of the ventilating system. This natural convective effect should be added to the above developed computer program to produce an approximate ventilation performance prediction system. Such a system must be able to include new openings in walls (windows, floors, or roofs produced by the fire itself.

3.1.6.3.4 Develop practical ventilation criteria for use in building codes and by which new building designs could be tested. Again in this area as under structures, present knowledge now is or soon could be capable of at least partial design and detailed performance prediction by computer. These programs are essential to the research to test the general validity of our ideas. However they also offer design and performance prediction possibilities of great practical importance. Their widespread potential use, eventually by specification in fire codes is so promising that the NBS should take steps to bring the power, potential, and limitations of ventilating system performance prediction to the attention of the engineering public by demonstration.

3.1.6.4 Sprinkler System - to determine where and how automatic sprinklers should be used as a building system.

The automatic sprinkler system has had a greater effect on decreasing the loss by fire than any other single thing. Its effect has been so dramatic in fact that some fire protection people seem to believe that it is THE answer to the fire problem. While its importance as now used should not be belittled, its present limitations and problems should be recognized. The fires that occur in sprinklered buildings are often stopped while they are very small - opening a few heads only. Many of the big fires - 10% of the fires account for 90% of the fire loss - became big fires because for one reason or another some portion of the sprinkler system did not work. Most of the reasons are operational; the water valve was closed for some minor purpose and someone forgot to open it again, the firemen shut the valve when the fire was judged to be out - but it wasn't. These blunders are under continuous attack by all fire protection agencies whose efforts are to be applauded and perhaps in some areas assisted by grants for educational and other public awareness campaigns. However some of the really large fire losses occur in spite of the sprinkler system. What went wrong is not currently known. In most fires, the water damage exceeds in value the fire damage (but not the fire damage that would have occurred if there were no sprinklers). Too many heads open and at present none of them can sense that the fire is out and shut itself off. The piping system's fittings are frequently cast iron which is easily broken by structural deflection of the building. And the most important question, why are so many buildings without this most effective fire deterrent? The installation cost is, of course, the direct answer. However, a very important question remains; namely, what is the resultant economic value of automatic sprinkler systems from an individual and from society's point of view? Detailed questions of sprinkler head design and operation are considered in a later section. In this section only the sprinkler system as a building component is considered.

3.1.6.4.1 Collect and analyze data on accidental fires so as to learn exactly how and why a few fires get away from the sprinkler system. This study would disclose the nature of the failure; social, human, automatic system response, or a technical gadget which could lead either directly or indirectly to a solution.

3.1.6.4.2 Analyze fire loss data to disclose the economic advantages and disadvantages of automatic sprinklers. Compare this with the cost of sprinkler installations to provide exact information on the economics of sprinklers. This would show either the size of the economic gap that must be met if sprinklers are to become universal or would provide powerful arguments in favor of more complete sprinkler coverage of fire risks. These economic studies should be made concurrently with the loss of value and other studies mentioned elsewhere.

3.1.6.4.3 Study the heating of sprinkler piping systems. The exact knowledge of the time-temperature history for the sprinkler system components might make possible the use of cheaper materials or cheaper methods of manufacture and installation. Relatively simple use of available heat transfer data should provide accurate predictions of performance which should then be experimentally checked in a few cases.

3.1.6.4.4 Examine fire detection systems from the point of view of sprinkler turn on and shut off. Can any current devices sense an extinguished fire reliably enough to be used to shut the sprinkler (local head and/or branch system) off? If not what are the technical problems requiring solution? What is the cost-benefit ratio of a more sophisticated automatic sprinkler system? What is the highest detector system cost at which they could pay for themselves in loss reduction so that they would be worth using; for which occupancies?

3.1.6.5 Detection and Alarm Systems - to develop the requirements for and performance of fire detection and alarm systems as building components.

The detection of a fire is useless unless the automatic detector has something useful to do with the information. Thus the communication system is an essential part of the total system. Only system problems are considered here. Detailed problems are discussed below in 3.1.7.1.

3.1.6.5.1 Study fire data to determine the effectiveness of detection systems in reporting fires, the causes of failure to do so, the frequency of false alarms, the probability that a fire is started by a short in the alarm system, the kind of and cures for improper human response, the economic cost-effectiveness data for detectors, response of occupants to the alarm, etc.

3.1.6.5.2 Study possibility and cost-effectiveness requirements for more advanced detection and alarm systems. Build detectors into all light fixtures, build detectors into house wiring, have detectors turn on appropriate sprinklers and report to the appropriate fire house by an alarm and full information as to the locations within which building the fire exists, etc.

3.1.6.6 Domestic Water System

Fire data should be studied to detect fire problems, if any, associated with domestic water systems. New types of problems may arise from the use of new materials. For example, the use of plastic pipe may permit electric charge build up in relatively insulated parts of a water system during electric storms thus giving rise to fire producing discharges in the building.

3.1.6.7 Waste Disposal Systems

Fire data should be studied to detect fire problems associated with these systems. Soiled clothing or rubbish chutes could serve as smoke and fire spreading ducts while the use of non-metallic pipe should be examined to determine whether it is a fire hazard.

3.1.6.8 Electric Systems and Appliances

These systems are connected with fire in two ways. They may serve as the source of ignition to start a fire or they may prevent the proper functioning of other systems because of a power failure. Thus lights, elevators, ventilation equipment, door operating devices and even the fire detection and alarm systems may be affected. Much good work has already been done on these problems and generally the mere recognition of a new problem is sufficient to assure new work. Again the systematic analysis of fire data would help locate new problems and an occasional exploratory or demonstration test may be required.

3.1.6.9 Heating and Cooling Systems (fuel, furnace, chimney, air conditioner, distribution system, controls)

Heating systems necessarily work with fire hazardous materials and it is essential that the controls be fail safe in design. Much commercial effort goes into these problems and the most important new work required is in data collection and analysis to disclose shortcomings of present equipment.

3.1.6.10 Communication Systems

The fire failure of a communication system is associated with either the burn through of a wire or the failure of a fire report to go through central promptly. Two kinds of questions arise which should be answered by fire statistics or new fire tests.

3.1.6.10.1 Data should be sought on the average length of time between a fire start and the failure of the communication systems. This should correlate with the average fire start location and the nearest average communication system wire location since the latter has almost no fire resistance.

3.1.6.10.2 Data should also be sought to learn the average and statistical fluctuation of the delay time between pick up of a phone to report a fire and the response of the fire department. The large majority - approaching 100% - of fires are reported by phone and presumably this works very well. In addition to equipment failures, failures may be caused by delays in the communication central, (manned or automatic), delays at the fire house, failure of the reporting party to give name and address. Perhaps there should be excess capacity to prevent any possible overload to the communication system. Perhaps the fire call should go to a central computer which would not only ring the alarm at the appropriate fire house but would inform the fireman automatically of the address and number of the reporting phone.

3.1.6.11 Comfort and Beauty. As the affluence of our society increases these items loom more and more important and can account for a significant fraction of the value of a property and may on occasion present special fire hazard. Special materials used in furniture, acoustic tiles, rugs, etc., need continual attention for ignition and fire spread properties, combustible and toxic gas production, etc. In addition, continuous attention is needed to be sure that fire prevention items are made available in sufficiently attractive form that comfort or beauty considerations do not rule them out. For example, fire sprinklers are omitted or are placed in an inoperable location because they don't look nice, or because of appearance, fire extinguishing equipment is placed in hidden locations where it is unknown or forgotten in an emergency.

3.1.7 Detection & Alarm Devices - to provide a foolproof, instantaneous and discriminating fire locating, detecting, and reporting system.

The prompt detection and signaling of the presence of an unwanted fire is of vital importance both with regard to human safety and limitation of property loss. Recognizing this, many manufacturers have devised and marketed a wide variety of useful detection and alarm devices. It is beyond the field of responsibility of the Center to provide the public with information on the relative merits of competitive devices operating on similar principles. It is considered appropriate, however, that the Center develop and make available information of a technical nature to show the advantages as well as deficiencies of detection devices which operate on different physical or chemical processes. Such work will require the development of a greatly refined understanding of evaluation or test methods for such devices. The work will require new understanding of decomposition products, transport phenomena, convection throughout an enclosure as influenced by a building's construction and ventilation system, details of radiation production early in a fire and of its spectral and time dependent properties, in short, all of this whole research program as related to the ignition and early growth stages of a fire and its interaction with the building in which it occurs. Some problems not studied elsewhere are:

3.1.7.1 Development of new detection principles - to devise methods of increased sensitivity and discrimination for fire detection.

Present detection devices sense a rise of temperature, a rate of rise of temperature, the 5-30 cycle/sec radiation fluctuation of a flame, or the smoke obscuration or ion capture capacity. These phenomena permit design of excellent detectors for many purposes. However different kinds of smoke call for different kinds of response. Some may be essentially free of false alarms, etc.

3.1.7.1.1 Chemical detection devices. These may take the form of chemical or electrical systems responsive to minute amounts of chemical odors. It may be useful to explore biological systems since some of these are known to possess systems capable of producing an electrical response to very specific chemical substances in extremely minute amounts. Perhaps these systems can be in some way imitated.

3.1.7.1.2 Microwave detection of ionization. The detection of flame ionization by radiation techniques, if it proves to be possible, would be most useful to locate fires under floors, behind walls, or in partitions. Whether or not such detection is possible before smoke can be measured can be learned only by an extensive research by a group with special competence in modern microwave techniques.

3.1.7.1.3 Spectrally sensitive detectors. By the simultaneous use of several different spectral bands more discriminating detectors may be possible.

3.1.7.1.4 Mixed Detection Systems. Explore the use of various combinations of sensing elements to attain higher reliability in detecting fires, thus avoiding false alarms.

3.1.7.2 Performance measurement methods - to evalute, revise, and devise detector rating tests.

It has been shown that while some new and very sensitive detection devices may be developed, the assessment of their merit may be limited by the application of traditional test methods. It is therefore important to develop performance measurement methods which provide an objective assessment of the usefulness of a detection device. The usefulness of such measurement methods must be rationalized and justified on technical grounds when data on relative performance are reported as a result of use of such methods. In addition, suitable test fire models should be devised to give an absolute performance rating to detectors for use in a wide range of fire situations.

3.1.7.3 New alarm methods and their merit - to evaluate present alarm systems and devise new approaches.

Investigations must be made of new and more reliable and effective ways of transferring the information that a fire is developing to the agent which will react to this information and take protective steps. The possible use of radio links, automatic or manual signals transmitted on power or telephone lines, etc., should be explored and their relative merits studied. The fire detection system of every building should eventually be hooked up with a city computer which could then spread the alarm in many new ways and assist in many respects with the rapid dispatch of appropriate fire units. It could for example drop a map of the building in question including an X to mark the location of the calling detector into the first truck to leave the station and could regulate the traffic lights for the best route to the fire. Feasibility studies and perhaps some special demonstrations are needed in this area.

3.1.7.4 Alarm system performance - to determine the adequacy of present alarm systems.

Fire loss data will be analysed as to the performance of present alarm systems. Are call boxes any longer needed? If so, where and under what conditions? Does the telephone alarm system perform at maximum efficiency? Could call boxes be economically replaced by public phones from which fire and police calls are free and simpler to make - i.e., break a glass and push a button to make the emergency call.

3.1.8 Fire Suppression - to identify more effective ways of controlling and extinguishing fires.

While we have found ways of extinguishing fires and reducing the flammability or ease of ignition of materials, the methods used can seldom be considered efficient. In addition, many parts of the research undertaken under this outline will clarify the technical phenomena of fires to the point that new methods and devices should be forthcoming. The fire fighting techniques and operations making optimum use of present equipment and knowledge have not yet been systematically explored and an optimum sought. Many differences now exist within the fire services among which the best under various fire circumstances should be sought.

3.1.8.1 Extinguishment - to develop a quantitative predictive understanding of the fire extinguishment process.

The extinguishment process is at present understood in qualitative terms: cool the fire, remove fuel, exclude oxygen. Essentially a fire is really out only after all fuel is cold, and the purpose of all extinguishment research is to quantitatively learn the process by which the going fire is eventually reduced to cold fuel.

This work should include study of the response of the various fire processes to every kind of ambient interference in the hope that new extinguishment approaches may be discovered. Studies will include:

3.1.8.1.1 The growth of a cold spot. Water or other coolant produces a cold spot or area in a fire environment, study the conditions under which this spot reheats and reignites. Through such studies define the conditions under which the cold spot may be encouraged to persist and grow by suppressing the reactions in adjacent fuel.

3.1.8.1.2 Distribution of applied water (or other extinguishant) on and within a burning material at various fire stages.

Absorption of water, evaporation of water. Determine criteria for reignition from inside the fuel vs. reignition along the fuel surface vs. reignition by ambient fire environment. The effect of the extinguishing agent on cooling of the fuel, altering the thermal decomposition process, excluding oxygen, adding side reactions (water gas reaction for example) etc.

3.1.8.1.3 Study effect of drop size (mostly water).

Determine the fate of drops of various sizes - singly and multiply. The motion and evaporation of drops in a fire situation influences the convection and its temperature. These interrelations are important in suggesting the optimum drop size, if the drop is to get through to the fire or if it is desired to control the hot gas temperature to prevent fire spread or sprinkler openings. The fate of a drop in the fuel determines its effect on fire extinguishment. Study the details of what happens to a drop in various types of burning fuels at various times during a fire.

3.1.8.1.4 Drop size determination. The actual drop size distribution produced by various practical devices, nozzles, fog nozzles, sprinkler heads of various designs. Determine how the drop size distributions can be altered to improve the efficiency of use of water in fire extinguishment.

3.1.8.1.5 Determine properties of foam. Action of foaming agent. Flow of foam in pipes and nozzles, flow of layer of foam over liquid fuel, over a floor, flow of foams through rooms, doors, etc. Mechanism of foam fire extinguishment. Use of vitiated air in foam production. Improvement of foam adherence, foam endurance, foam blanketing, foam insulation.

3.1.8.1.6 Determine mechanism of dry powder fire extinguishment. Follow powder particle through the fire convection and into the fire to see where it goes and what it does. Does it adhere to the fuel? Melt and soak in? Spread over the surface? Are the decomposition or combustion reactions of the fuel altered? etc.

3.1.8.1.7 Improved volumetric smothering methods such as foam inerting or chemically active gas inerting.

3.1.8.2 Fire Fighting Equipment - to conduct research necessary for development of new and improved equipment for use by fire fighters.

There is a real need for research pointing toward ways in which the work and efficiency of the Fire Fighter can be improved. Some innovations which seem to merit consideration include:

3.1.8.2.1 Improved self-contained breathing equipment to provide a longer useful operating period, better visibility, means for communication when using such units.

3.1.8.2.2 Improved fire location devices. Infra-red, microwave and echo location devices all appear to have merit.

3.1.8.2.3 Improved fire engine design simplifying pumper operation and control, providing remote indication of fire ladder erection and location, etc.

3.1.8.2.4 Improvements in fire clothing for the purpose of achieving greater mobility and safety for the wearer. Provide the maximum possible safety from excess heat (radiation absorption) and fatigue (weight).

3.1.8.2.5 Remote control nozzles for operation from dangerous locations.

3.1.8.2.6 Fire robot for occasional very dangerous jobs.

3.1.8.2.7 Computerized information handling - detection, automatic extinguishing, fire spread, fire safety.

3.1.8.2.8 Explore all fire fighting equipment now in use from the point of view of its adequacy for the purpose for which it is used. For example, the snorkel basket should be redesigned to permit ready entry of people from window ledges and ready exit on the ground.

3.1.9 Instrumentation - to develop the means to measure more things more accurately in laboratory and field.

Spectacular technical progress often results from the introduction of new instrumentation. Such changes result from an ability to really measure and understand a phenomenon where previously only guesses were available.

The fire problem needs two general types of instrument innovations, one directed towards an improved capability to measure and gain basic understanding of fire behavior and the other towards the development of methods of measurement of appropriate characteristics of real fires to aid in the process of saving life, control, and extinguishment. As usual, any instrumentation found to be good by laboratory use will immediately be used for field fire research if the device can be made sufficiently portable. On the other hand, the area of fire measurements for the assistance of fire fighting is non-existent at the present time. A fireman looks at the building involved, makes qualitative guesses as to where the fire is, how it is progressing and what extinguishment attack would be appropriate. At present, in fact, it is not clear just what measurements would be of benefit. However, as our knowledge of fire and its characteristics improves and indicating instruments are improved, quantitative uses will appear. Oxygen, and toxic gas indicators would show the need for breathing apparatus, radiation meters could have an integrated response which could ring an alarm when the ignition of an adjacent building was imminent, a structural vibration measurement might show impending structural collapse, etc.

Some of the currently visualized instrumentation needs are mentioned below.

3.1.9.1 Heat flow sensors - to accurately measure heat flux.

There are numerous commercially available sensors on the market but most of them have been developed for use under thermal conditions quite unlike, and much less severe than, those involved in fire research studies. Typical units required include:

3.1.9.1.1 Heat flux tranducers to measure heat flow between the fire environment and an exposed structural or other solid or liquid surface.

3.1.9.1.2 Radiometers to provide better selectivity for radiant heat flux rather than the sum of radiant and convection heat flux. More rugged instruments are required with capability for accurate measurements even under prolonged exposures to heat and varying ambient conditions. Radiometers of various degrees of spectral sensitivity will be required as the research progresses.

3.1.9.1.3 Heat rate calorimeters are urgently required for measurement of heat release rates of materials or assemblies under going fire conditions. Such devices would permit measuring the extent to which materials and assemblies of them participate in a fire resulting from an external exposure.

3.1.9.1.4 Heat integrators of some kind are required for measuring the "fire exposure severity", i.e., that fire parameter which is found to be related to fire damage. Such integrators would provide a useful way of comparing the intensity-duration characteristic of experimental fires.

3.1.9.2 Mass Flow - to accurately measure mass flux.

The heat balance between generation and loss during a fire is largely influenced by fuel and air feed rates or the mass flow through the fire zone. Our ability to measure such mass flow is seriously limited by the transient nature of the phenomena and the fact that many fires of interest are not usually of a closed system type. Needs in this area include:

3.1.9.2.1 Improved gas flow measuring methods which are independent of the thermal variations in the surroundings.

3.1.9.2.2 Volumetric flow measurement methods, velocity, area, and time integrating techniques must be devised to provide rapid readout of varying flow pheonmena during short time fire experiments.

3.1.9.2.3 Aerosol flow measurements are of great importance for studies of extinguishing behavior of both disperse solid chemicals and water sprays. Improved instrumentation in this field would be of great value.

3.1.9.3 Particle size - to develop a rapid means of particle size and density measurement.

The behavior of fires when exposed to sprays and fogs is largely a function of the particle sizes of these dispersed water sprays. It becomes important, therefore, that measurement techniques be developed to permit rapid measurements of particle size, density, and distribution in dispersions of both solids and liquids. New instrumentation should permit measurements of:

(a) Natural and artificial fog particles

(b) Particle size of chemicals used for fire fighting

(c) Smoke particulate matter

(d) Water from sprinklers, nozzles, etc.

3.1.9.4 Temperature - to develop practical methods of measurement and display of rapidly varying temperature space fields.

While great progress has been made in the development of simple, accurate and reliable temperature measuring devices a need remains for improved ways in which they can be used to measure thermal conditions during fire experiments. These include:

3.1.9.4.1 Improved and simplified logging equipment for recording a large number, perhaps thousands of temperature measurements, during large scale fire studies. Such instrumentation should be suitable for both field and laboratory use.

3.1.9.4.2 Space temperature scanners to provide a much clearer picture of conditions throughout the volume of fire involved space. New methods of data reduction and presentation via a computer may be necessary.

3.1.9.4.3 Data plotting and processing equipment for both field and laboratory use, for rapid analysis and indication of fire development and behavior.

3.1.9.5 Strain & Motion Instruments - to accurately measure stress and strain under fire conditions.

The movements and strains developed in structures or components of them often have major influence on the fire behavior of the system. The currently available instrumentation is however so temperature sensitive that its use poses severe limitations on the variety and type of measurements which can be made. There is thus a need for development of new, simple, and accurate sensors for making such measurements under the adverse conditions existing during a fire.

There is special need for instruments that could be installed rapidly on the structure of an existing building that is to be test burned.

3.1.9.6 Chemical Analytical Instruments - to replace where possible the slow analytical chemical processes now available by more rapid portable methods.

Fire, because it converts gaseous, liquid, or solid fuels into gases of modified chemical nature, can present a safety problem through generation of toxic hazards. It is important, therefore, to have chemical analytical methods which are both accurate and practical to use for both field and laboratory work. It has not yet been possible in the laboratory to show through analytical measurements, a material balance before and after combustion of some of the common plastic materials now in use. Not only is it important that our instrumentation and understanding of the problems involved be developed to the stage that this is possible, but techniques must be evolved to make such measurements on a rapid or continuous basis. New instruments of increased sensitivity are necessary for both field and laboratory measurements. Such devices must be capable of continuous sampling and recording so that a complete time history of the products is available.

3.1.10 Human Factors - to learn how to fit fire education, training, and equipment, to the people who must use it.

The activities of people have a major influence on whether fires start. When fires do start the responses of humans often affect the ability to egress, the efficiency of operating fire equipment, the human decisions, actions, and capabilities. Thus people and their interrelationship with the fire problem are an important subject for investigation by the Center. Aspects of the human-fire relationships should include:

3.1.10.1 Response of populations to fire prevention media and methods.

3.1.10.2 Response of fire service populations to training and educational methods.

3.1.10.3 Response of populations under fire stress, i.e., defining criteria of "flight-or-fight" responses.

3.1.10.3.1 Perception (of fire exits, or corrective action) changes induced by stress of fire situation.

3.1.10.3.2 Physiological tolerance modification by phsychological stress of fire.

3.1.10.4 Sociological factors affecting fire incidence.

3.1.10.5 Human engineering

3.1.10.5.1 Definition of fire service population anthropometric and physiologic characteristics for background in equipment design.

3.1.10.5.2 Development of information on ease of operation, safety of use, maintainability and error commission for the guidance of fire equipment manufacturers.

3.1.10.5.3 Analyses of firemen - fire equipment interactions as background for 3.1.10.5.2. This is applicable not just to new types of fire equipment but rather is especially applicable to types now in use. Firemen find much that is wrong with every piece of equipment they acquire and these complaints must be analyzed for their legitimacy and for possible cures.

3.1.11 Fire Operations - to use rational methods to achieve minimization of the total fire cost.

The planned application of systems analysis techniques to fire problems has seldom been practiced. In spite of this, such studies seem likely to be highly useful for reducing the burden of unwanted fires. The minimization of the cost to society of the fire problem can only be carried out in its full effectiveness by applying operations analysis techniques to the entire fire prevention, operations, loss, replacement system. However so ambitious a program is at present far from possible in a useful form because of insufficient data on the components of the system. Thus each of the various parts must be studied in detail and the essential cost and loss data accumulated as a function of all significant variables; personal, social, technical. Following this, application of the data to various parts of the system as suggested by the titles below can be made both to prove out the data and to begin making useful contributions to total cost reduction. Much later the entire fire problem as a complex system can hopefully be treated. The principal areas which seem promising for study by these methods include:

3.1.11.1 Operations analysis of existing fire departments - to determine the best organization and response technique. These studies must be carried out for various sized urban, suburban and rural areas.

3.1.11.1.1 Operations

There is a need to study the existing emergency and nonemergency operations of various sized fire departments. Operation analyses will facilitate a comprehensive, systematic understanding of the functions currently performed by fire departments and their manner of implementation. These analyses will provide bases for recommending modifications to improve present operational capabilities. Specific areas of investigation include:

3.1.11.1.1.1 Fire prevention. The present role of fire prevention and its relationship with fire control and suppression and fire protection in general.

3.1.11.1.1.2 Fire control and suppression. The present role of fire control and suppression and its relationship with fire prevention and fire protection in general. Also includes operations analysis of fire ground operations.

3.1.11.1.1.3 Information processing. The means whereby data are put into the fire department system, the manner in which they are processed, the process of making decisions, and action mechanisms available. This includes among other things consideration of command-and-control operations during emergencies and the dispatching function.

3.1.11.1.1.4 Interdependence effects. Includes both intraactional and interactional effects of operations (e.g., response time effect on fire control and suppression function).

3.1.11.1.2 Organization

Organizational features of fire departments need to be assessed as they relate to departmental effectiveness. This includes consideration of organizational arrangements (e.g., chain of command, standing operating procedures) and procedures. This will yield comprehensive, systematic information about currently existing organizational characteristics from which recommendations for improving operations can be made.

3.1.11.2 Systems analyses of fire prevention, control, and suppression.

3.1.11.2.1 Fire prevention. Systems analysis provides optimal models toward which existing fire department organizations and operations can be patterned. A system analysis of the fire prevention subsystem is needed to provide this frame of reference. In particular, information would be acquired that would allow for a better determination of the optimal relationship between fire prevention and fire control and suppression. Also, included would be an assessment of interactions between urban design, codes, land use, municipal water systems, and fire departments.

3.1.11.2.2 Fire control and suppression. The fire suppression and-control subsystem requires system analysis for the same reasons as for fire prevention. Specific areas of investigation include:

3.1.11.2.2.1 Information processing. All the general considerations as previously given apply, with particular consideration of warning systems (i.e., detection and alarm systems). Information requirements in general, and command-and- control information in particular are included for investigation since they are critical for effective operations.

3.1.11.2.2.2 Fire department response. This entails the assessment of factors contributing to the time of response of a fire department to the locale of the emergency. Factors include reporting systems, communications media, dispatching, and response behavior of fire units (i.e., fire companies and fire-department auxiliary units).

3.1.11.2.2.3 Fire ground operations. This involves system analyses of fire ground operations to determine optimal tactical configurations and personnel actions under various types of geographical, structural, and departmental modes of operation, and fires.

3.1.11.2.2.4 Organization. This includes consideration of manpower distribution, chain of command, functions, operations (e.g., municipal, regional), as they relate to fire department effectiveness.

3.1.11.2.2.5 Equipment replacement and innovation. The numerous potentialities of current technology need to be considered more fully in the design and specifications for fire department hardware. In particular, the technological gains realized by the military establishment and the aerospace industry need to be investigated for their application to the fire service since they are readily available and have demonstrated value. These include advancements in both the physical and behavioral sciences.

3.1.11.2.2.6 Personnel policies and strategies. The acquisition, training, development, and promotion of personnel need to be related to the results of system analysis. This approach would facilitate the formulation of personnel requirements responsive to present and future needs for manpower, both qualitatively and quantitatively.

3.1.11.2.2.7 Fire Fighting techniques and strategies. The approach of the fire company to the fire varies considerably from city to city. The best strategy needs to be sought by analysis of the effectiveness of various approaches. Study is needed on equipment used, fight from inside or outside, ventilate, use special extinguishing agents, etc.

3.1.11.3 Urban fire prevention and control system analyses - to determine interactions between urban design, codes, land use, municipal water systems, fire departments.

3.1.11.4 Municipal fire grading system analyses to determine the nature and distribution of the fire hazard for purposes of fire protection improvement.

3.1.11.5 Municipal fire protection analysis (response to above)

3.1.11.6 Urban design factors to reduce fire protection costs

3.1.11.7 Economics of integral building fire safety or municipal fire protection

3.1.11.8 Basic concepts for egress from burning buildings

3.1.11.9 Budget design for minimum total cost

3.1.12 Medical Investigation - to find out what the health hazards are and what can be done to minimize their effect.

The Public Health Service is currently supporting a large diverse research program on various aspects of public health and safety. There has, as yet, however been little evidence of a unified program directed towards understanding and defining the health hazard associated with fire problems. The Center will probably not be in a position to assume the responsibility for funding all the work required, but it should employ and maintain a staff competent in sensing and defining the needs for research in this area. The group will be charged not only with defining the research required, but must be capable and effective in interpreting both Center and non-Center sponsored work in the medical field as relevant to life safety during fires.

The work of this Section will include but not be confined to:

3.1.12.1 Mixed Gas Toxicity

Investigations related to defining the toxic hazards associated with a large range of combustion by-products and their mixtures. While much work has been done on investigation of maximum acceptable safe concentrations of various gases mixed with air for various exposure periods, there is almost no information on the effects of synergism in modifying the hazard when typical mixtures of products are present.

3.1.12.2 Causes of Fire Deaths

Studies directed towards more adequate and reliable methods of defining the phenomena, mechanisms, or agents responsible for fire fatalities.

3.2 Fire Safety and Information

The two main objectives of this part of the work of the NBS Fire Center are to collect and analyze data on the fire problem as it now exists and to reduce the number and severity of fires by supplying fire information of all kinds to those who could use it. In this part of the program even more than in the research part 3.1, many and varied organizations are already well advanced in most parts of what needs to be done. Thus the role of the NBS is in large part to study the field to detect any significant needs not now being met - or being met inadequately - and to supplement current work by some properly placed in house efforts, or more often by contract with some outside competent and interested group.

3.2.1 Fire Loss Experience - to find out how bad the fire problem really is and why.

Before any decisions can be made on what needs to be done to reduce fire losses of life and property, the nature and magnitude of the real problem must be known. For many purposes, the fire data already assembled by the National Fire

Protection Association and the Public Health Service provides the necessary information with adequate precision. However in order to make detailed analyses of such things as, the needs and priorities for improvements, the impact of introduction of new industrial products, and the effect of innovations proposed as a result of fire research work, much broader based and more detailed data collection and analysis are desirable. These problems have been recognized for years by those now collecting and organizing fire data and in spite of their best efforts data in useful form is collectable from only about 20 out of the 50 states. The adoption of a uniform system for collecting and reporting fire data by all of the states should be promoted through the recently-established National Conference of States on Building Standards and Codes. Additional statistically significant data will from time to time be required on specific technical subjects and must in general be obtained by special acquisition teams. Questions of details of ignition or fire behavior, the economics of rate of value destruction in typical occupancies, the effectiveness of fire fighting tactics, etc. will be needed by the research program and would be collected jointly with those directly concerned as described in Part 3.1. Many more detailed statistical analyses of the meaning of the data are now possible by use of large scale modern computers. The Fire Center will provide financial support both for the additional data collection and for computerized data handling required as well as to support the employment of actuarial experts to carry out new statistical analyses and to extract the maximum significance from the data collected as well as to insure that all technical data needs on the fire loss experience of the country are being adequately met.

The work of this section will be carried out largely by contracts and fund transfer with the appropriate organizations. Some of the problems to receive attention are:

3.2.1.1 Casualties - to learn more about how many people are fire casulaties and why.

3.2.1.1.1 Injuries - Investigations of a type currently being conducted on only a very limited scale by the Public Health Service. Such investigations should be enlarged to present an indication of both regional and national experience on serious fire-associated injuries. Techniques should be sought for the conduct of such investigations by simpler and more economical methods which nevertheless still yield technically sensitive and useful information. Special attention needs to be given to the collection of those pieces of information which would shed light on why injuries occur. Was the detection or alarm inadequate? Did the fire spread too fast? Were escape routes inadequate or blocked through carelessness or by smoke? Were escape route signs inadequate or were the people confused because of fear? Were there too many people - a panic? What additional data of significance can be collected in order to get at the cause of fire injuries? Some of the information can no doubt be obtained through normal channels. However it may be necessary to create special data forms to be completed by the injured themselves and in some cases a personal interview may be necessary.

3.2.1.1.2 Fatalities - The Bureau of Vital Statistics collects information on fatalities directly associated with fires. These statistics should be examined for their adequacy and the Bureau of Vital Statistics should be urged to introduce improvements when desirable and possible. For example, they should be urged to include in death certificates information on any previous fire, accident, or serious illness experienced by the individual which could have been contributory to the fatality. This would permit the analysis of the interaction of fire hazards with other potential causes of death.

3.2.1.2 Property Loss - to learn more about how much property is lost by fire.

More complete property loss records and more complete statistically significant analyses of the data collected are needed.

3.2.1.2.1 Increased detail on technical and economic problems associated with the accidental fire is urgently needed, especially relative to the rate of loss of value during the course of the "average" fire in various occupancies and the change in this rate of loss by extinguishment activities. These analyses would be coordinated with that under 3.1.1.

3.2.1.2.2 Improved methods are required in achieving both uniformity and detail as well as comprehensive coverage of fire loss information. Such information must be directed toward achievement of both a national and regional picture of fire loss experience. The type and organization of the data collected should include what is necessary for improved international comparisons of fire loss. This should be accomplished by working closely with international fire data groups already in existence.

Cooperation with the NFPA Fire Statistics Section and the state Fire Marshals is essential in this area of improved data collection.

3.2.1.3 Fire Loss Analysis - to find out why the fire loss is so big.

Data from all sources must be analyzed in such a way that the significant causes of fire loss are disclosed. Both the public and the Government could make direct use of some of this information in order to achieve loss reduction through fire department changes, code changes, materials changes, etc. The Fire Center will need as much of such analyses as it can get so as to properly direct its efforts and priorities on all aspects of its work so as to assure future fire loss reduction.

Some of the questions which need detailed study are; Why did certain small fires grow into big ones? What did or did not happen? Why was the extinguishment action inadequate? Did the alarm system or water supply fail? Was the building design, construction, use at fault? Were the sprinklers wrongly placed or inadequate for some reason? And these same questions must be studied also for a statistically significant sample of small fires. Why didn't the small fire grow bigger? What was done or happened correctly in both the typical and atypical low loss case which might give a hint on how to catch and stop more fires while they are small.

The Fire Center will maintain a group skilled in statistical analyses in order to make the most out of data available and to detect potential data improvements.

3.2.2 Fire Hazard Analysis - to determine the fire potential of our industries and our homes both urban and rural.

There is an urgent need to develop effective methods of relating the use of devices, materials, and assemblies or systems with the fire hazard they represent. The most common way of doing this is to learn by use. This has, in many instances, been an expensive procedure in human casualty and dollar units. It is proposed, therefore, that a group be established to make advanced studies and rationalizations on the fire hazards related with existing, and new or proposed, operations and structures. Such studies require the collection of data on buildings, their furnishings, and use as they now exist. The group would have to follow trends in materials, city planning, building design, personal habits as related to fire hazard so as to assess future dangers.

This group will have broad interactions with other portions of the Fire Center. The work on ignition, fire growth and spread, characterization of materials, the smoke movement through buildings, the psychology of panic, etc. are all essential to a fire hazard assessment. Without a full knowledge of these research topics, the hazard evaluation will overrate some items, underrate others and miss a few items completely. Thus at present only an interim hazard analysis can be made. As new research knowledge becomes available the ratings can be improved. Furthermore the attempt to make hazard ratings may well disclose additional research problems which should find a place in the research program.

This group because of its wide acquaintance with both hazards as they exist, and the technical progress being made to understand them will have a major advisory responsibility in connection with proposals for new standards, codes or other legal restrictions.

The staff assigned to conduct this work must be skilled in a very broad range of technical competence including: economics, human behavior, physics, chemistry, toxicology, safety engineering, systems analysis, computer science, etc. and hence must include specialists borrowed from time to time from various technical sections. Every effort will be made to define the hazards by analytic and rational methods rather than the arbitrary decisions so often necessary in the past. Examples of areas in which this type of work would be of value include hazard evaluation for:

3.2.2.1 Surface flammable materials

3.2.2.2 Smoke and toxic product producing materials

3.2.2.3 Combustible materials for interior finish

3.2.2.4 Fire load and distribution

3.2.2.5 Fire endurance of structures

3.2.2.6 Fire fighting techniques

3.2.2.7 Fire protective procedures

3.2.2.8 Fire performance of ventilating systems

3.2.2.9 Adequacy of and fire safety of exits

3.2.2.10 Fire performance of other building systems

3.2.2.11 City planning for fire hazard reduction

3.2.3 Fire Education - to put available information into the hands of those who need to know.

3.2.3.1 Public Safety - to make the public aware of their contribution to the fire problem.

Much has been done by NFPA and others to create in the public an awareness of fire hazard and safety problems. While this work has undoubtedly served to save many lives there is a real need to increase total activity of this type as well as its effectiveness. Procedures for reaching the public and impressing the public are many and varied and change with changing conditions. Considerable effort has been spent in trying to improve advertising. These efforts should be examined to find the best ways to reach the public. Public safety programs are carried out in many countries in different ways. These too should be surveyed for new ideas. All of the approaches now used should be intensified to produce greater effect.

It is expected that the major portion of this work will be done through contract with others. The Fire Center should consider proposals to produce more and better fire prevention radio and TV programs, movie shorts (cartoons?) for inclusion in motion picture theater programs, longer movies with text material for use in elementary and high schools.

An important educational step for the public is in operations that affect them directly. Fire inspection work now done by firemen should perhaps be extended to more frequently include a home inspection service (at the request of the home owner) and the distribution of up to date general information on availability and economics of detection systems, fire extinguisher location, etc., to the home owner to assist him in deciding whether or not additional fire protection is warrented. This information would be of a general nature not directed toward comparisons of products. At present the interested home owner must hunt for such information. Instead of this, it should be hard to avoid. The fire center should be receptive to proposals to try new approaches in these or other directions as they arise.

3.2.3.2 Fire Accident Hazard Education - to make the public aware of their danger from fire.

Many fire casualties result from lack of public recognition of the hazards involved. This lack of recognition extends all the way from a failure to clean up fire hazards in attics and basements, to properly handle fuel, to properly keep open means of egress, to the proper first aid treatment of those exposed to toxic gases or burned. The center must, therefore, assume a leading role in support of more adequate education of the public in recognizing and avoiding those actions and hazard accumulations which lead to fire accidents. The public must be induced to take elementary fire prevention precautions and to properly provide first aid to those who have suffered in a fire accident.

3.2.3.3 Technical Fire Education - to provide college level courses.

There are at present only two universities in the country which provide courses leading to a degree of fire protection engineering and the majority of the students (about 30 per year total) are there because full scholarships are available, not because they either wish to be in or intend to enter the fire protection field as a career.

All engineering fields are developing so rapidly that engineering education is becoming more and more general - thus more and more alike - for all engineering specialists. Students are interested in a broad engineering education rather than intensive specialization. A greater number of specialized first degree programs in fire protection engineering would probably not improve the fire protection field since it would not assure more or better students.

A perhaps more serious deficiency is the lack of good technical fire protection courses at both graduate and undergraduate levels available to students being trained for work in related fields such as architectural planning and design, city management, civil and industrial engineering, etc. Even if such courses existed today, very few students would take them. It must be recognized that so long as the fire protection field is almost entirely dominated by codes and standards of an empirical, often arbitrary kind, the attitude of logically minded students will continue to be negative while those more directly concerned with a specific career will say "the answer is in the handbook, I don't need to waste time learning it." Only as the understanding of fire and fire loss becomes more based upon sound scientific and economic principles and data, and the codes can be rewritten in terms of clearly logical rather than seemingly arbitrary requirements will it be possible to prepare such an exciting fire protection course that students will eagerly seek it out rather than be forced to take it. The modern student, very wisely, wants to know why - why should I take that course, it's all in the handbook.

It will be an objective of the Fire Center to stimulate and foster the creation of suitable technical fire courses in appropriate areas as soon as the accumulating knowledge of the science, technology, economics, and human factors make it possible.

3.2.3.4 Fire Service Training - to bring to every fireman the knowledge and training appropriate to his work.

Fire departments organized as they are by cities and rural areas and in many cases of a volunteer nature, are not in a position to provide the kind of training their men should have for best performance. In some states there are attempts made at a state level to provide such training. However, practices vary widely both in the United States and abroad. In several European countries and in Japan a national fire school exists to bring to some, in some cases all, firemen and fire officers a knowledge of the best up-to-date equipment, tactics, and organization.

The Fire Center should take such steps as will make available to the fire services the knowledge they need. This would be done through various approaches such as:

3.2.3.4.1 The encouragement of good, exciting technical fire courses at the university level so as to induce students to adopt the fire service as a career.

3.2.3.4.2 Provision of support for development of more adequate fire service training as an extension service of state universities.

3.2.3.4.3 Support the development of a National (or several Regional) Fire Academy for the training of firemen in the knowledge and techniques of fire tactics, organization, and management required of a fire officer.

3.2.3.4.4 The development of special training devices to be distributed to and used by local fire departments to assist the personnel, especially of the volunteer type to improve their fire fighting capability.

3.2.3.4.5 Through seminars and special city management courses to educate city officials on the necessity of improved training for their fire fighting personnel so that municipal training budgets can at least purchase training texts and other elementary materials. Eventually it will be desirable for city officials to realize the importance of special training for firemen whose ability and ambition indicate their potential as a fire department officer. This will become increasingly important as the fire fighting equipment increases in sophistication, the operations are assisted by computers, and the budgets are scrutinized by operations analysis techniques.

3.2.3.5 Fire Center Seminars - to disseminate knowledge of new fire protection and safety engineering developments.

The Fire Center would conduct seminars at appropriate times for advanced technical training of the selected staff of various academic and fire fighting organizations. Such training would be confined to in-depth description, discussion and demonstration of new or complex developments in the science of fire protection and safety engineering. Such seminars would not be confined to presentation of ideas, and devices conceived at the Fire Center, but would rather be held whenever developments anywhere warranted it.

3.2.3.6 Fire Research Seminars - to discuss research results with peers

The Fire Center will from time to time hold seminars on various specialized technical subjects with the key technical personnel of other public and private groups for the purpose of discussing the detailed nature of specific problems, the presentation of research results and the clarification of the best direction of future effort. Such seminars would be held on an ad hoc basis and would be independent of the National Bureau of Standards technical advisory panel structure.

3.2.4 Fire Demonstration and Evaluations - to assist in the introduction of new techniques or devices.

The art of fire protection engineering has been developed over a long period primarily as a result of experience and intuition although on occasion it has benefited by limited technical investigations. The understanding developed has usually been adopted as the basis for building and other municipal code requirements, and because of this it has on occasion been difficult for innovators to achieve prompt recognition of their contributions in the field of fire service. It is essential to encourage innovators since only through their efforts do new ideas originate.

It is proposed, therefore, that the Fire Center would assist in evaluation and, where appropriate, the introduction of new improved techniques for both fire fighting and fire protection engineering. Such work could be conducted at the NBS as part of the activities of the Center but probably more often would be supported through contract with others. The following are illustrative of the type of developments which might warrant support:

3.2.4.1 Full scale demonstration of value of new type of fire fighting device such as a gas inerting agent.

3.2.4.2 Full scale demonstration of the potentialities of a new type of fire detector.

3.2.4.3 Demonstration of a new fire retardant treatment method for clothing fabrics.

3.2.4.4 Demonstrations available to the public on the nature of fire hazards and how to avoid them.

3.2.4.5 Demonstration of improved building construction methods for confinement of fire and its by-products and the protection of the occupants and their safe egress.

3.2.4.6 The production of and distribution for demonstration purposes to fire fighters of limited numbers of a new communication device.

3.2.5 Fire Science Information - to make the world's fire literature available to all.

3.2.5.1 Fire Center Library - to make the world's fire literature handy to the Federal Government and the Fire Center.

The Fire Center would develop and maintain a complete and useful technical library in the field of fire protection and safety. This library would provide a source of fire information for Federal Government fire prevention people, for the Fire Center Staff, and for interlibrary loans.

3.2.5.2 Support for Other Libraries - to make the world's fire literature handy to others.

Certain other organizations, such as the National Fire Protection Association and universities, which will find the maintenance of libraries primarily directed towards fire protection and safety desirable, will receive support from the Center when this seems appropriate to the national interest.

4 Alternatives.

4.1 Cooperative and Sponsored Research at Foreign and U.S. Laboratories.

During the past year the fire research consultant visited and studied the program of 61 fire laboratories, academies, and departments in 14 countries. Twenty-six of these institutions are in the United States. Fire practices and research programs vary widely. Only in Japan and England are there laboratories with a sufficiently general charter and sufficiently sustained financing to make a general attack on the fire problem possible. In these two countries their fire program relative to the problem is comparable to their work in other technological areas.

Before concluding that the United States should follow England and Japan, it should be observed that in most technical fields a technological gap has developed between the United States and other advanced nations. This problem has developed because the U.S. has since World War II, put more and more scientific manpower to work on the advanced technological problems in many fields. This indicates that if this country is really serious about fighting the fire problem by modern methods, it cannot merely emulate the best that others do but must devise, initiate, and support a fire research program with cost-benefits comparable to that shown by its efforts in other fields. The program outlined in the previous section 3.1 was devised to emulate in the fire field the eminently successful U.S. efforts in other modern technology fields.

As in other fields, there are desirable programs of a cooperative international nature. So it is in the fire field. However, again as in other fields, it is better both from considerations of dollar drain and the possession of the resultant know how to arrange frequent conferences and interchange of personnel rather than to contract fire research abroad. The interchange of personnel could well be arranged on a formal sabbatical basis since this would assure the best possible interchange of data, procedures, and results. Cooperation in the fire protection field often takes the form of dividing an experimental problem into parts with each laboratory taking one part. Such cooperation should continue and be encouraged. The amount of work required in many parts of the proposed fire research and safety program is so large that all interested groups should be encouraged, sometimes supported, to contribute to our knowledge. In some areas, as for example in the use of fire structural test furnaces, fundamental work should be encouraged in all the U. S. laboratories; however, their furnace time is in general very heavily engaged in commercial test work so that only limited fundamental studies can be undertaken. On the other hand, NBS should engage in no structural rating tests; its efforts should be geared solely to fundamental fire structural studies and the development of improved test methods. Thus the existence of furnaces elsewhere does not cover the needs of the fire research program. In fact the NBS should also work on these problems with more flexible-type furnaces. In other areas, as the study of fire problems in high-rise buildings, there exists nothing in the United States at this time which can serve this purpose, so new facilities must be built.

Should all the proposed facilities be built for the NBS? Obviously they could be scattered all over the United States and put under the control of many different groups. Unless the fire problem is viewed in the narrow, limited sense of the past, such dispersal is not wise. The proper forward-looking approach is to encourage the building of duplicate (but modified) facilities in other places too. In the development of the modern aircraft gas turbine, duplicate facilities were built in many places (directly or indirectly at government expense). By thus bringing many thinking men in many groups into these problems, the U.S. engines are now the best in the world in spite of a World War II head start in Britain. Fewer "competing" groups are needed in the fire area to do an equally complete job since the proprietary rights problem causing complete duplication in secret in the engine field is much smaller, often non-existant in the fire field. The NBS needs a complete set of research facilities as do other groups as well.

4.2 Research Recommendations

4.2.1 That there be extensive cooperation between the Fire Center and laboratories abroad, including technical assistance to under-developed nations.

4.2.2 That there be a modest sabbatical-type program for the Fire Center research staff providing personnel interchange with other laboratories both in the U.S. and abroad.

4.2.3 That the financing of fire research abroad be considered only when a truly exceptional research idea is proposed by an outstanding research man. In general, foreign nations should be encouraged to support their own research so as to narrow the technological gap.

4.2.4 That research and other activities of the Fire Center be done on contract whenever suitable, well conceived ideas are proposed by U.S. state or municipal organizations, by universities, by non-profit laboratories, or by other groups as permitted by Congressional action.

4.2.5 That when circumstances warrant, contracts to outside groups permit them to construct suitable fire research facilities.

4.2.6 That facilities be built at NBS as needed to carry out a good fire research program as described in 3.1.

4.3 Cooperative and sponsored participation in the Fire Safety and Information Program by Foreign and U. S. Groups. In the broad areas of fire statistics, fire education, and demonstrations, the degree of cooperation with foreign nations is limited to comparisons of methods of attack and of effectiveness of results. Again international groups are already active in many of these areas and various groups in the U.S., especially the NBS, already participate whenever possible.

When it comes to work in the United States, it is expected that a very large fraction of the work outlined in section

3.2 will be performed by groups outside of the NBS. The Fire Center should not set out to gather general loss statistics. They should instead stand ready to assist in trying to get more states to supply better fire data and to participate directly and/or through contract with its analysis.

The Fire Center should not set out to establish a Fire Academy. They should instead stand ready to assist one or several regional colleges to set up educational courses or programs. It would be expected that these would eventually be self-supporting,at least to the same extent as other college programs. However, financial assistance will be essential to get started. Educational programs of various other types may be set up in various ways, but in most cases this should be by contract in response to good unsolicited proposals or by support of proposals requested to fill a recognized gap.

The NBS should be ready to assist with the evaluation and demonstration of new fire protection methods and devices. These might be of the "invented here" type, but more often they will be in support of ideas of outside groups. If a device of some kind is involved, only rarely would NBS construct the demonstration items. More often this would be done on contract.

In the information and education part of the Fire Center's activities, the importance of supporting outside groups has been repeatedly stressed. This is so not only because many of these groups already have extensive experience and know better how their part of the fire problem can use additional support, but also because many of these problems have special regional or local character best known only to a regional or local group.

4.4 <u>Information and Training Recommendations</u>

4.4.1 That there be extensive cooperation between the Fire Center and various groups abroad which deal with similar Information and Training problems.

4.4.2 That the present fire data collection by NFPA, HEW, and others be encouraged by additional contract or transfer of funds if necessary. This would include the support of special investigating teams when they are engaged in the study of general fire data collection problems.

4.4.3 That NBS should add its voice to those already calling for more complete state participation in fire record collection.

4.4.4 That methods be sought to set up by contract at some already existing fire academy or college a National, or several Regional, Fire Academies for fireman and/or fire officer training.

4.4.5 That the fire library at NBS be made as complete a national facility as possible, but in no sense be regarded as replacing the essential services already supplied by other existing fire libraries. In fact, other libraries should be urged to build up their fire collections and to institute modern computer information handling methods as these become available. The NBS should assist with financing as appropriate.

4.4.6 That in the fire information and safety work, the NBS confine its efforts largely to contract monitoring to assure a good program as described in 3.2.

5 Personnel and Funding

In order to carry out the proposed program of the Fire Research and Safety Center described in section 3, a large and varied staff is required. Each item of the program has been examined and the necessary staff has been listed. This cannot be done in a very precise way. In the first place, the program if viable will not be static. It will not have static needs. These will change as the work proceeds. Secondly, the program as outlined has not considered the fine details of exactly how each item will be started. The program will be altered in various ways while being set up. These changes will cause changes in the personnel and budget requirements; however, these would be expected to be small.

5.1 The Personnel and Funding Required for the Proposed Fire Program

Table 5.1 summarizes the results. The first and second columns give the estimate of professional and subprofessional staff required to carry out the proposed research. Whenever a significant part of the work is expected to be done by contract, the personnel listed includes only contract monitoring plus some secretarial services. The numbers do not include general service personnel, building maintenance, shops, etc., nor general Fire Center administration. It should be noted that various parts of the technical program could, and in appropriate cases would, be carried out by contract if suitable proposals are received. If none are received, they must be done in-house. Thus, a modest portion of the personnel and their share of the budget, as listed, may be on contract instead of at the fire center.

The 3rd column gives the required budget calculated at $30,000 per man year. This sum is based upon NBS experience

Table 5.1 IN-HOUSE PERSONNEL AND TOTAL FUNDING REQUIRED FOR THE FIRE RESEARCH PROGRAM

Program Element	Prof.	Subprof.	Recommended In-House Budget* ($K)	Recommended Contract Budget ($K)
3.1 Fire Research and Engineering				
1. Problem Identification	5	3	240	100
2. Ignition	19	16	1,050	1,000
3. Fire Growth & Spread	37	43	2,400	1,500
4. Combustion Products-Life Safety	14	12	780	1,000
5. Fire Characteristics of Materials	21	29	1,500	1,000
6. Fire and Building Systems	36	29	1,950	1,600
7. Detection and Alarm Devices	7	7	420	300
8. Fire Suppression	19	23	1,260	1,660
9. Instrumentation	11	10	630	200
10. Human Factors	11	4	450	800
11. Fire Operations	26	14	1,200	1,400
12. Medical Investigation	2	1	90	200
SUBTOTAL	208	191	11,970	10,760
3.2 Fire Safety and Information				
1. Fire Loss Experience	5	2	210	8,500
2. Fire Hazard Analysis	10	3	390	--
3. Fire Education	8	3	330	15,600
4. Fire Demonstrations and Evaluations	6	9	450	7,500
5. Fire Science Information	3	3	180	1,510
SUBTOTAL	32	20	1,560	33,110
Fire Specimen Preparation	3	17	600	--
GRAND TOTAL	471		14,130	43,870
ANNUAL BUDGET			58,000	

* Some of this will be used to support out of house research when appropriate proposals are received.

and covers salaries, overhead and expendables. To the in-house budget must be added the sums required to support the expected contract research. This is anticipated to be about three times the in-house figure. Thus the total budget of the Fire Research and Safety Center required to support the program recommended is on the order of $58 million dollars per year. This budget could not be effectively used until the facilities are ready and a staff is employed. This will take on the order of five years.

Although $14.13 million, as given in Table 5.1, might be spent in-house, it is anticipated that a number of universities, non-profit laboratories, and other organizations will make research proposals worthy of support. This might well drop the in-house portion to the order of $10 million. The 4th column of Table 1 gives the recommended contract budget by program element. It contemplates the largest sum to be used for more effective public education, fireman training, and education and training aids.

When one looks at these budgets, the budgets of present fire research laboratories around the world, and the budget of the present NBS fire research effort, it is all too obvious why the modern advances of technology have been slow in finding their way into fire protection practices. Even the proposed budget of the Fire Research and Safety Act of 1968 falls far short of what is required to do the job.

5.2 Priorities

However, Congress may decide not to support the total program; and it will be necessary for the NBS to do what it can with less. To assist the NBS to select a rate of effort on various parts of the proposed program which can be supported at various levels of funding, Table 5.2 has been assembled. This table gives at the top four different levels of total support. Below this figure appears the "in-house" portion with the same understanding as above, i.e., some modest but unpredictable portion of this will probably be done on contract.

To specify the recommended priorities at each of the funding levels, the table lists the number of professional staff recommended on each of the major program topics.

5.3 Personnel and Funding Recommendations

5.3.1 That the NBS carry out the best possible program with whatever funding level Congress decides upon.

5.3.2 However, that the NBS point out the grave deficiencies in their program for any funding level less than that required for the recommended program herein.

6 New Facilities at the National Bureau of Standards

6.1 General Features of Facilities Requirements

In order to carry out the in-house portion of the proposed research program, facilities will be required at Gaithersburg and elsewhere. The recommended facilities are listed in the following section 6.2. In each case there is given the portion of the fire program which it serves, the general description, and any special features required by the research to be done.

Since fire research often involves considerable smoke, soot, water, foam, etc., these factors must be considered in placing the research buildings. It is desirable for all of the fire facilities to be close together since some of the research personnel will need, at various times, more than one facility. Furthermore, there are real merits in promoting frequent informal contacts between working level people in different parts of the program. All of the fire research involving room size or smaller fires can be accommodated at Gaithersburg by providing one or more buildings with smoke abatement equipment. (See 6.2)

For some work, however, this presents a special problem. The high rise building (6.2.3) will not be the source of more than the smoke from one burning room. However, a ten-story

Table 5.2 PROGRAM PRIORITIES. PROFESSIONAL PERSONNEL AT NBS ON EACH PART OF THE PROGRAM AT EACH FUNDING LEVEL

Total Budget (millions)	$ 58	$21	$ 8	$ 4
"Inhouse" Budget (millions)	14.13	5.3	2	1
5.2.1 Fire Research and Engineering				
1. Problem Identification	5	2	1	1
2. Ignition	19	8	2	1
3. Fire Growth and Spread	37	14	6	2
4. Combustion Products - Life Safety	14	4	2	1
5. Fire Characteristics of Materials	21	7	2	1
6. Fire and Building Systems	38	15	5	2
7. Detection and Alarm Devices	7	2	1	0
8. Fire Suppression	19	7	4	2
9. Instrumentation	11	6	2	1
10. Human Factors	11	4	2	1
11. Fire Operations	26	8	3	1
12. Medical Investigation	2	1	0	0
Subtotal	209	78	30	13
5.2.2 Fire Safety and Information				
1. Fire Loss Experience	5	2	1	0
2. Fire Hazard Analysis	10	2	1	1
3. Fire Training	8	3	1	1
4. Fire Demonstrations	6	1	1	1
5. Fire Science Information	3	2	1	1
Subtotal	32	10	5	4
Total Research Professionals (5.2.1 and 5.2.2)	242	88	35	17

building cannot be put inside of another building sufficiently large to permit realistic study of wind effects on building ventilation, etc. The burning of dwelling size fires or large "as built" structural fire tests are too large again to permit enclosure and also would on occasion produce smoke in such quantity that reasonable size smoke removal equipment would be swamped.

These larger fire tests would not be performed on a rapid schedule. Once a month is perhaps a reasonable maximum frequency, and perhaps for this rate the zoning restrictions at Gaithersburg would permit a variance.

6.2 Required Facilities

6.2.1 Experimental Fire Research Building or Buildings (Facility No. 1)

Location: Gaithersburg - adjacent to Specimen Preparation Building and Storage Area (Facility No. 8)

Function: A large fire test enclosure or enclosures for the research programs on fire growth and spread; combustion products and life safety; fire and building systems; detection and alarm devices; fire suppression.

Construction: Reinforced concrete or steel frame, totally enclosed. Two-hour fire rating.

Fire Research Spaces Required:

Fire Spread Model Research	Area	Minimum Height
10' x 10' x 8' room plus models 3/4, 1/2, 1/4, 1/10, etc. scale. Each room needs 20' free space around it but free space may overlap.	4000'	20'
Fire room with corridor 10' x 10' x 8' + 6' x 60' x 8'	3000'	20'
Fire room with corridor 3/4 scale model	2000'	20'
Fire room with 2nd floor room and facade 3 stories high	3000'	50'
Fire room with 2nd floor room and 3 story facade, 3/4 scale model	2500'	50'
Property Value Destruction Rate		
10' x 10' x 8' room plus models 3/4, 1/2, 1/4, 1/10, etc. scale. Each needs 20' free space around it but free space may overlap	4000'	20'

Smoke Production and Movement

10' x 10' x 8' room plus models 3/4, 1/2, 1/4, 1/10, etc. scale. Each needs 20' free space around it but free space may overlap. (1/3 of this area should be high ceiling)	3000'	20' 50'

Ventilation study

fire and control area	1500'	50'

Sprinkler study

30' x 30' variable ceiling height to 30' and control area	1500'	30'

Detector study

30' x 30' variable ceiling height to 30' and control area	1500'	30'

Foam and Dry powder test

1/3 of this area should be high ceiling	3000'	20' 50'

Fire equipment demonstration and test

1/3 of this area should be high ceiling	3000'	20' 50'

Resultant Total Requirement - Sq. ft.

Space at 20' height	19,000
Space at 30' height	3,000
Space at 50' height	10,000

Special facilities

Fire fighting water supply and floor drains
Smoke Abatement
The smoke vent to an after burner must be available at each test site independent of other test sites. Never more than 1/3 would operate at one time. One test should be able to be performed while another is in preparation. Thus areas should be sufficiently separate so that only the area in test gets smoked up and is open to cold air in winter.

6.2.2 Test Area for Burning Buildings (Facility No. 2)

Location: Remote site or "once-a-month" at Gaithersburg.

Function: An outdoor area for the burn-out of dwelling-sized buildings in connection with the research programs of fire growth and spread; combustion products and life safety; fire and building systems; detection and alarm systems; fire suppression.

Description: Outdoor site of at least 250,000 sq. ft. with a circling buffer zone 250 ft. around the site. The site should contain both level and hillside locations for the dwelling-sized burn-out buildings. The area within a 2,000-ft. radius of the site should be relatively flat, so that there will be the aerodynamic conditions which will assure wind flow with a uniform velocity distribution across the test site. Buildings may be used on prepared burn-out sites, repeatedly used, or on foundations specially built for the test.

Special Facilities:

Two prepared burn-out sites.
One 40-ft. dia. turntable with a fire-protected top face for positioning the burn-out building relative to the direction of the wind.
Fire fighting water and storage reservoir. Sufficient site drainage.
Available fire-fighting equipment.

6.2.3 <u>High-rise Fire Test Building</u> (Facility No. 3)

Location: Remote area or "once-a-month" test at Gaithersburg.

Function: A full-scale high-rise building in which can be reproduced full-scale fire conditions for research on fire growth and spread; combustion products and life safety; fire and building systems; detection and alarm devices; fire suppression.

Size: 30' x 30' x 10 stories high with additional columns and rooms on three levels.

Construction: Reinforced concrete.

Fire rating: 4-hour.

Special construction features:
Fire wall on one face.
Removable and exchangeable exterior wall panels.
Fire brick protection of structure on first, fifth, and tenth stories.
Interior elevator shaft.
Interior stair well.
Anchored steel vertical skids on four faces of building for the attachment of platforms and instrumentation.

Recessed door frame inserts on each door opening to mount removable and exchangeable doors.
Vertical ventilating shafts (3 required) with opening on every floor. Openings closed with removable concrete plugs.
3 ventilation blowers for both blowing and exhaust as required. 2 on roof, 1 on ground.

Building services:
Pipe wells with removable concrete covers on each floor and exhaust fan on roof.
Electric power and fire fighting water outlets on every floor.
Arrangements for simulating various types of air handling and distributing systems for buildings and studying smoke and firespread thereby.

Special equipment:
Ten-story service tower with construction skip-type elevator outside and adjacent to fire-wall face of building.
Hammerhead crane, 10-ton capacity, on circular track on roof of building.
Supply of fire fighting water

6.2.4 <u>Forced Convection Fire Effects Facility</u> (Facility No. 4)

Location: Remote area or at Gaithersburg using smoke abatement device in, but separated by partitions from, Experimental Fire Research Building (Facility No. 1)

Function: A wind tunnel in which the effects of a controlled wind could be investigated in the research programs on fire growth and spread; combustion products and life safety.

Construction: Reinforced concrete or steel frame, enclosed. Two-hour fire rating.

Special Facilities:
Wind Tunnel: 12' x 12' x 20' working section usable either open or closed. 50 miles/hour horizontal wind speed. Smooth nozzle intake from atmosphere, clear of intake interference, exhaust fan to atmosphere. Work area adjacent to tunnel working section (about 1/2 on each side) 2000' sq. ft. This Facility could partially overlap free areas of Experimental Fire Research Building (Facility No. 1). This does not have to be a high aerodynamic performance device; no calming section, no turbulence control, commercial exhaust fans for drive. Must be able to provide controlled wind speed down to one mile/hour.
Sprinkler system, manually controlled, and floor drains in tunnel working section.
Instrument and observation room adjacent to tunnel working section.

6.2.5 Structural Fire Research Building (Facility No. 5)

Location: Gaithersburg.

Function: A building enclosure containing large furnaces for fire-edurance tests and fire investigations of building structures and members to determine the general fire-imposed requirements of building systems.

Construction: Reinforced concrete or steel frame, enclosed. Two-hour fire rating.

Special Facilities:
Structural fire research space required:

	Floor Area	Height under Crane Hook
Floor panel and building subassembly Research furnace (space 50' x 100' x 50')	5000'	50'
Wall panel research furnace (space 40' x 50' x 30')	2000'	30'
Column research furnace and subassemblys (space 40' x 40' x 50')	1600'	50'
Space for model structural fire research	3000'	30'

Total space requirement:
Space at 30' height 5000 sq. ft.
Space at 50' 6000 sq. ft.

Maximum temperature of furnaces: 2,300 - 2,500 F.
Cranes: 30-Ton service over test area.
Smoke abatement devices and exhaust system capable of exhausting each furnace area separately.
Fire protection system including fire fighting water and floor drains.
5 - Laboratory modules.
Instrument shop.
General service shop.

Special Utilities: Fuel gas for furnaces and heavy-duty electric power for heating panels.

6.2.6 Structural Fire Test Floor (Facility No. 6)

Location: Remote area or "once-month" at Gaithersburg.

Function: A heavy structural test floor on which full- or large-scale structures can be built and loaded under burn conditions to study the general fire-imposed requirements of building systems.

Construction: Reinforced concrete structural test floor open to the outdoors atmosphere. The test floor would be 60' x 60' x 12' deep and built in the form of a cellular box structure with the loading equipment contained in the cellular spaces. Fifty-ton loading points would be located at 5-ft. centers.

Special Facilities:
Gas burners on 5-ft. centers.
Fire fighting water with reservoir storage and provision for drainage of fire fighting water away from the test area.
Fire-fighting equipment available.
Mobile crane lifting a 30-Ton load at a 35-ft. radius to a 50-ft. height.
A small office and services building, properly fire-protected, close to the test floor to contain (1) an instrument and observation room, (2) an instrument shop, (3) a general service shop, and (4) two laboratory modules.

Special Utilities:
Jacks and necessary hydraulic loading equipment.
Large supply of fuel gas for burners.

6.2.7 Self-heating Rooms (Facility No. 7)

Location: Gaithersburg. Could be located in the Experimental Fire Research Building (Facility No. 1).

Function: Enclosed rooms for research on ignition by self-heating.

Construction: Reinforced concrete or steel frame, enclosed. Four-hour fire rating.

Special Facilities:
Four - 15' x 15' x 15' self-heating rooms in a larger temperature-controlled room for spontaneous combustion investigations. Roof removable to permit loading and unloading contents of rooms by overhead crane.
Controlled temperatures in the research spaces up to 200 F.
Exhaust fans for smoke removal through a smoke abatement device.
Sprinkler system, manually controlled, and floor drains in the self-heating rooms and surrounding space.
Instrument and observation room adjacent to self-heating rooms.
Instrument shop.
General service shop.

6.2.8 Instrumented Trucks (Facility No. 8)

Location: Location of portable equipment determined by need.

Function: The instrumented trucks will provide a portable assemblage of recording and data processing instrumentation which can be moved to the test locations at Gaithersburg, the remote area, or a field test site.

Number of trucks:
- One - Truck for general fire investigation studies.
- One - Truck for field fire tests.
- One - Truck for field fire-structural tests.

Special equipment (to be developed at NBS under instrumentation procurement):
Portable generator

6.2.9 Specimen Preparation Building and Storage Area (Facility No. 9)

Location: Gaithersburg - adjacent to the Experimental Fire Research Building or Buildings (Facility No. 1) and the Structural Fire Research Building (Facility No. 5).

Function: This building would provide in a central location a facility for use by present and future installations of the Building Research Division (1) in grading, storing, and mixing or fabricating materials of a known and controlled uniform grade for the construction of structural components for testing and (2) in storing components already tested.

Construction: Reinforced concrete or steel frame building, enclosed with a two-hour fire rating. Paved storage yard.

Functional Areas: Storage of materials, mixing of materials, specimen fabrication, curing rooms (four), temporary storage of prepared specimens, and storage of tested specimens. Of these (4) curing rooms, two are for concrete specimens and two are for wood specimens and lumber storage. One kiln drying oven for concrete or wood specimens up to 4' x 4' x 60' in size.

Space Requirements:

Storage and curing	15,000 sq. ft.
Fabrication	10,000 sq. ft.
Total	25,000 sq. ft.

Special Facilities:
- 3 - laboratory modules for materials control and testing.
- 30-Ton crane serving entire building and portions of Storage Area.

30-Ton transfer car and tracks from Storage Area to Experimental Fire Research Building (Facility No. 1) and Structural Fire Research Building (Facility No. 5).

5-Ton fork lift for outdoor Storage Area.
Tool, equipment, and instrument storage rooms.

6.2.10 Fire Research and Safety Building (Facility No. 10)

Location: Gaithersburg.

Function: Housing for administrative personnel for the Fire Center, small laboratories, and the Fire Safety and Information Office (including the Fire Records Office).

Construction: Reinforced concrete or steel frame building, enclosed, similar to the general-purpose office and laboratory building now existent at Gaithersburg.

Office Facilities:
Administrative offices of the Center.
200 - office modules for research personnel.
Fire Records Office: Three office modules and three file storage modules.

Special Facilities:
50 - laboratory modules.
Gas, water, electric power, hoods, and ventilation to laboratory modules.
Service and instrumentation shops: 3,000 sq. ft.

6.2.11 Data Recording and Handling Facility (Facility No. 11)

Location: Gaithersburg

Function: Building area for data recording, handling, and real time computing facility for 1,000 input channels at a total of 10,000 readings per second.

Construction: Reinforced concrete or steel frame building similar to general-purpose office and laboratory building now existent at Gaithersburg.

Special Facilities:
Power as needed by computer and recorders.
Data link cables to every experimental fire facility and to other facilities as well if, as is recommended, the data handling capacity is made large enough for multipurpose use.
Air conditioning as required by the equipment.

6.3 Facilities Cost Estimate

The estimated cost for design and construction of the facilities described in Section 6.2, together with the cost of furnishings, equipment, and occupancy are summarized in Table 5.3.

It would be most desirable from our operating standpoint to have all of the buildings and facilities on one site. However, the need for limiting air pollution will probably dictate that some of the facilities be located at a remote site where open fire burning is permissible. The estimates in Table 5.3 are made on the assumption that the Test Area for Burning Buildings (Facility 2), the High-Rise Fire Test Building (Facility 3), and the Structural Fire Test Floor (Facility 6), will be located on such a remote site, and will be located in a plot of approximately 30 acres to provide suitable wind conditions at the location of the fire.

In addition, the Experimental Fire Research Building (Facility 1), and the Structural Fire Research Building (Facility 5), will require smoke abatement apparatus of large capacity. However, the air pollution generated by these two facilities was believed to be manageable with suitably designed particulate separators and gas scrubbers.

As many as seven separate structures are indicated in Section 6.2 to provide all of the research capabilities required for the fire research program. However, it is quite probable that several of the facilities (e.g., Facilities 1, 4, 7 can be economically brought together in a single building by the architect.

The total cost for design, construction, and occupancy of the proposed facilities is estimated at $28,466K broken down as follows:

Land acquistion	$ 100K
A&E services	1,440K
Construction	23,590K
Equipment	2,835K
Furniture and furnishings	76K
Moving and occupancy	425K
Total	$28,466K

Table 5.3 COST ESTIMATE FOR DESIGN, CONSTRUCTION, EQUIPMENT AND OCCUPANCY

	Facilities	A&E Design	Construction	Technical Equipment	Furniture & Furnishings	Moving & Occupancy
1.	Experimental Fire Research Building	$ 480K	$ 7,900K c/	c/	$ 20K	$ 150K
2.	Test Area for Burning Buildings a/	20K	330K	Turntable, 1500 ft^2 office incl.	2K	10K
3.	High Rise Fire Test Building a/	50K	740K	Tower only	6K	20K
4.	Forced Convection Fire Effects Facility	20K	b/	400K	4K	10K
5.	Structural Fire Research Building	230K	3,880K d/	2000K e/	4K	80K
6.	Structural Fire Test Floor a/	20K	290K	400 ft^2 office, incl. 35K jacks	2K	5K
7.	Self-heating Rooms	b/	b/			
8.	Instrumented Trucks	b/	b/	200K		
9.	Specimen Preparation & Storage Area	220K	3,650K	Crane incl.	2K	50K
10.	Fire Research & Safety Building	400K	6,800K		36K	100K
11.	Data Recording and Handling Facility	b/	b/	200K		
	TOTALS	$1,440K	$23,590K	$2,835K	$ 76K	$425K

a/ These facilities to be located remote from Gaithersburg because of high smoke generation. A 30-acre site will be required, at an estimated cost of $100K.

b/ Part of Facility 1.

c/ Includes $2,000K for smoke abatement.

d/ Includes $1,360K for smoke abatement.

e/ Estimated cost of floor, wall and column furnaces.

6.4 Facilities Recommendations

6.4.1 That fire research facilities described under section 6.2 be provided in support of the Fire Center Program.

6.4.2 That steps be taken immediately to ascertain the permissible limits of open burning at Gaithersburg.

6.4.3 That, if there are serious limitations (to less than once a month) to open fires at Gaithersburg, steps be taken to locate a suitable remote site of sufficient size to permit open fire burning without restriction for the foreseeable future.

6.4.4 That, if appropriations for all of the facilities described in section 6.2 cannot be made available at one time, the order of priority in construction follow that shown in Table 5.4.

7 General Recommendations

Because of the unavoidable air pollution problem of all large scale fire test work, and the desirability of having all of the Fire Center work close together, a careful study should be made of the possibility of locating the entire Fire Center at a location where air pollution is not a problem; an island along the Atlantic coast where the prevailing winds would blow smoke seaward, or a western mountainous or desert location where the closeness of neighbors would be limited. Such a location would lose the close contact of the Fire Center to the rest of the National Bureau of Standards but the Center will be large enough to have problems of maintaining adequate contact between its own parts.

An acceptable remote location would have to be close enough to some large city so that the required personnel could be obtained and so that air transportation was good enough to make frequent contacts with other fire research groups possible and reasonably convenient.

Basically it is assumed that the "in-house" budget of the National Bureau of Standards is based upon total research staff calculated at $30,000 per man year. The planned contract research is assumed to be three times the above "in-house" budget. In fact, however, some of the money for "in-house" research may be let on contract when attractive proposals are received. The actual "in-house" work, will consume somewhat less than 25% of the total budget.

7.1 Recommended Facilities

7.1.1 That fire research facilities described in sections 6.1.1 through 6.2.10 be provided in support of the Fire Center Program.

Table 5.4

Order of Priority in Facility Construction

Priority	Facility	Facility No. (Section 6.2)
1	1/2 Experimental fire research building	1
2	Instrumented Trucks	8
3	Fire Research & Safety Building	10
4	Structural Fire Test Building	5
5	Specimen Preparation Building and Storing Area	9
6	Structural Fire Test Floor	6
7	High Rise Fire Test Building	3
8	1/2 Experimental fire research building	1
9	Data Recording and Handling Facility	11
10	Forced Convection Fire Effects Facility	4
11	Self-Heating Rooms	7
12	Test Area for burning buildings	2

7.1.2 That steps be taken immediately to ascertain the permissible limits of open burning at Gaithersburg.

7.1.3 That if open burning at Gaithersburg is limited to less than once a month or by other severe restrictions (e.g., to winter months), steps be taken to locate a suitable remote site of sufficient size (on the order of 30 acres) to permit open fire burning without restriction for the foreseeable future. Consideration should be given to the merits of building the entire Fire Center at the remote site.

7.2 Recommended Program

7.2.1 That the Fire Center use its best efforts to encourage, through financial assistance when necessary and appropriate, all groups both public and private to increase and improve their efforts to prevent and control fire losses.

7.2.2 That the Fire Center initiate work on the Fire Research and Safety Program described in section 3.

7.2.3 That research and other activities of the fire center be done on contract whenever suitable, well-conceived ideas are proposed by U.S., state, or numicipal organizations, by universities, by non-profit laboratories, or by other groups as permitted by Congressional action.

7.2.4 That when circumstances warrant, contracts to outside groups permit them to construct suitable fire research facilities.

7.2.5 That the present fire data collection by NFPA, NPHS and others be encouraged, by contract or fund transfers if necessary.

7.2.6 That the recently-established National Conference of States on Building Standards and Codes promote more complete state participation in fire record collection.

7.2.7 That methods be sought to set up by contract at some already existing fire academy or college, a National, or several regional, fire academies for firemen and/or fire officer training.

7.2.8 That there be extensive cooperation between the Fire Center and all groups abroad which deal with related problems in Research, Fire Information, or Training, including technical assistance to under-developed nations.

7.2.9 That the financing of fire research abroad be considered only when a truly exceptional research idea is proposed by an outstanding research man. In general, foreign nations should be encouraged to support their own research so as to narrow the technological gap.

7.2.10 That the Fire Center adopt a modest sabbatical type program for their research staff by providing personnel interchange with other laboratories both in the U.S. and abroad in order to encourage the most rapid and complete exchange of ideas and data.

7.2.11 That a Fire Library be established at NBS and be made as complete a national facility as possible, but in no sense be regarded as replacing the essential services already supplied by existing fire libraries.

7.2.12 That other fire libraries be encouraged to build up their fire collections and to institute modern computer information handling methods as these become available. The NBS should assist with financing as appropriate.

7.3 Recommended Priorities

7.3.1 That NBS seek funds to carry out the research program of section 3.

7.3.2 That the NBS point out the grave deficiencies in its program for any funding level less than that required for the recommended program herein.

7.3.3 That the Fire Center initiate its research program with the priorities as indicated by the total personnel and budget distribution as listed in table 1 of section 5.1.

7.3.4 That the Fire Center support its fire research and safety program as indicated by the order of facility construction priority given in Table 5.4, Section 6.4.4.

8 Conclusions

This report attempts to present for the first time, so far as is known, a complete picture of the needs of the fire research and safety problem. The program was developed without regard to who should carry out the work contemplated. The developed program assumes that the United States wishes to tackle the fire problem with the same technological vigor that has been used so successfully in many other areas of modern life.

The program and implied facilities do not contemplate work on a crash basis such as is necessary in military developments. A crash program would have to be something like five times larger but is not justified by the nature of the problem.

The large fraction of the work, approaching 80%, that is expected to be done on contract should bring to bear on the fire problem a greatly increased number of high caliber personnel, specialists in many fields of modern technology. Thus, over a period of time, the quality of fire prevention and control should be significantly improved; and new knowledge should provide the inspiration to invention of new devices and new techniques which should do away with or make simpler many of the prevention and control problems which result in the present high annual losses.

CHAPTER 6

Multiple Use of Facilities and Services

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Chapter 6

Multiple Use of Facilities and Services

1 Benefits of Multiple Use of Facilities

The capabilities of the new facilities have been reviewed to determine how many other research functions they could serve besides those for which they are to be specifically designed. The benefits of multiple use include:

a. Avoidance of unnecessary and costly duplication of facilities and equipment.

b. Better economy in operations through more frequent and steadier utilization of facilities.

c. Feasibility of developing a greater capability in a single facility than would exist in each of several small facilities.

d. Possibility of establishing facilities of an unusual character which no one laboratory could justify economically.

e. More opportunity for communication and pooling of ideas among engineers and scientists of different backgrounds leading to more innovation in research.

2 New Facilities Capable of Multiple Use

The new facilities described hereafter are capable of serving the functions indicated besides those for which they are to be designed.

2.1 Specimen Preparation Building and Storage Area (Fire Research Facility No. 9)

This factory-type building with heavy crane service is planned to provide a supply of building materials with controlled properties - materials of the kind that will be needed by all building research laboratories. A central plant of this kind does not now exist. Its other capabilities for the fabrication, curing and conditioning, and storage of specimens will be of particular advantage to the fire research, structural, acoustics and materials programs, as will also the ability to perform these services in the laboratory carrying out the test, when circumstances require insitu construction. This facility could construct specimens in size up to 30-ton floor slabs.

It is estimated that about two thirds of the output of this facility will be used by the fire research groups and one third by other IAT Sections.

2.2 High-Rise Fire Test Building (Fire Research Facility No. 3)

This ten-story shell of a building for fire research offers combinations of rooms and corridor and vertical shafts suitable for acoustics research. Another program not now possible because of the lack of a facility, the investigation of the performance of plumbing systems in high-rise buildings, could be carried out in this building without and with fire conditions.

2.3 Forced Convection Fire Effects Building (Fire Research Facility No. 4)

This wind tunnel with a large throat area and low-velocity airstream would be most useful for model studies of wind pressures on buildings and studies of acoustics in forced-air streams.

2.4 Structural Fire Test Building (Fire Research Facility No. 6)

In this laboratory, the heavy test floor for the loading of structures undergoing fire-endurance tests could also perform tests of a similar nature at room temperature. Moreover, the massive base provided by this test floor would be a good platform for acoustical and vibration tests of heavy floor and wall panels.

2.5 Instrumented Trucks (Fire Research Facility No. 8)

These trucks, carrying recording and other instruments for field fire tests and observations, could serve the same function for other building research laboratories as well as augmenting present instruments when needed.

2.6 Data Recording and Processing Center

This unusual facility would provide the following extensive capabilities:

- Up to 2,000 signal channels
- DC signals and AC signals within specified requirements
- Speed: 300 signals per second, max.
- Amplification of signals as required
- Scanning device, programmed through computer, to scan selectively
  - Signal peaks and valleys

- Readings differing by a programmed amount from the previous reading
- Every n-th signal

Output recorded on either magnetic tape or punched tape

On-line computer for (1) scanning, (2) read-out, and (3) data processing

Data processing for
- Reduction of data
- Summing up
- Averaging
- Computing to a given program
- Automated control of test during the experiment
- Signalling

Components of system
- Sensing devices or measuring gages
- Signal conditioning and calibration units
- Linear amplifiers
- Scanning device, computer programmed
- Analog to digital converter
- Digital processor (computer) with feedback to scanner
- Print-out
- Diesel generator unit in case of power failure

It is estimated that the use of this facility by the fire research groups and other IAT Sections will be sufficiently heavy to require almost all of its available time. Careful programming of requests for data processing will be necessary to schedule all demands for services.

2.7 Pool of Auxiliary Equipment

Auxiliary equipment, such as forklifts, traveling cranes, large tools, hoists, and miscellaneous construction devices will be needed for all the proposed facilities and would be available to the existing laboratories.

2.8 Multiple Use of Specimens

Floor, wall, and ceiling panels; structural members; and other structures, all fabricated for destructive tests, might first be used for non-destructive tests by the acoustics, structures, fire research, environmental, and materials laboratories.

2.9 Interchange of Test Data

The proposed facilities will make possible for the first time at the Bureau the subjecting of full-scale specimens to various tests, heretofore largely unrelated - for example, fire , structural, acoustical, and building-environment tests. Comparison of the properties derived by such tests might reveal correlations not now known to exist.

2.10 Services

The expanded research functions required by the proposed facilities, along with the existing laboratories, would provide a pool of services and personnel which could be shared as desirable and feasible.

3 Summary of Possible Multiple Use of Facilities and Services

The possible multiple uses of facilities and services just cited are summarized in Table 6.1.

TABLE 6.1 MULTIPLE USE OF FACILITIES AND SERVICES

Function	Fire Res. Facility	Clim. Exp. Facility	Acoustics Facility	Other IAT Labs.
ɔecimen Preparation & Storage				
Supply of controlled materials	x	x	x	All
Fabrication of specimens	x	x	x	Struc. & Mat'ls.
Curing and conditioning	x	x	x	"
Storage of specimens	x	x	x	"
On-test-site fabrication of specimens	x		x	"
igh-Rise Fire Test Bldg.	x		x	Plumbing
ɔrced Convection Fire Effects acility	x		x	Struc.
ructural Fire Test Floor	x		x	Struc.
nstrumented Trucks	x		x	Struc. & Envir.
nstrumentation, data collection & rocessing	x	x	x	All
uxiliary equipment (portable hand- ing equipment, large tools, etc.)	x	x	x	All
nterchange of test data	x	x	x	All
ultiple use of specimens	x		x	Struc. & Mt'ls.
ervices				
Engineering and drafting	x	x	x	All
Shops and mechanics	x	x	x	All
Reproduction of copy	x	x	x	All

CHAPTER 7

Discussion

The case for an agency of the Federal Government to undertake major research programs related to fire safety, acoustics, and materials deterioration and durability in building construction is rooted in a variety of historical, industrial, economic, and sociological phenomena which, taken together, indicate strongly that a national focus of leadership is required to realize the needed economic and public welfare benefits. Some of these phenomena are:

1. Building construction is basically a handcraft industry.
2. A very wide variety of natural and manufactured materials is used in buildings.
3. The building industry is comprised of a very large number of small, medium and large business enterprises.
4. Fire safety, acoustics, and durability are not properties of obvious sales appeal.
5. The fire safety and acoustical properties of a building are essentially systems problems of great complexity.
6. The deterioration of buildings is a long-term process depending on chemical and physical phenomena that are not well understood.
7. The building industry has no centralized research facility or organization.
8. Many of the physical features of buildings are regulated by municipal codes.
9. Some of the functional characteristics of building materials and components are in conflict with others.

Building construction began in this country with individuals or small groups of neighbors building their own buildings with the tools and materials readily available to them. As craftsmen came from Europe and new ones were trained by them in this country, building construction evolved more generally into a field erection process by many different crafts using factory-made or factory-finished materials. This has continued to be the dominant procedure of building construction, although there has been a growing trend during the last decade or two toward prefabrication of building elements, components, or subsystems in the factory. The field erection process has, in these instances, been a synthesis of elementary building materials and these larger subsystems. There is, at the present time, a significant percentage of mobile homes and other prefabricated designs of residences being produced for the small house market. Nevertheless, the building construction industry is still made up of a very large number of small entrepreneurs; medium and large contractors; materials processing and manufacturing enterprises of all sizes; small to large engineering and architectural firms; and trade unions.

A much wider variety of natural and manufactured materials is used in building construction than in a number of other large industries such as automobile and airplane manufacture, shipbuilding, etc. For example, many natural materials such as wood, clay, and stone are processed by molding, sizing, burning, finishing to size, or modified by additives to produce lumber, brick, cement block, clay tile, etc., which are fitted and assembled on the building site. Other items such as windows, doors, roof trusses, metal stairs, etc., have more of a custom-made characteristic with less latitude for fitting at the site. Mechanical items such as stoves, refrigerators, fans, furnaces, and air conditioners are largely factory-designed as a complete system and are merely attached or put in place at the site.

Thus, it can be argued that the evolution of the building construction industry from a handcraft origin and the wide diversification of materials and material processing used in building has inhibited large-scale cooperation in design, research, and standardization of assembled buildings or subsystems.

There are several hundred manufacturers associations and technical or professional societies in the building industry; approximately three hundred private research and testing facilities, more than one hundred colleges and universities, and approximately one hundred Federal, State and local agencies engaged in building research in the United States. Most of the manufacturers associations are product-oriented, and the standards produced by these organizations are usually limited to a particular component or class of materials, and thus deliberately avoid treating the interactions between different components or subsystems of a building. Private research and testing laboratories are employed to carry out specific investigations for private industry or public bodies under well-defined contracts. Various colleges, universities, and technological institutes perform research or design for industry on a consulting basis or have organizational units that carry out research programs for private or public bodies as an adjunct to their graduate education programs or as corporate subsidiaries separate from the education program. Federal, State and municipal building research activities are usually mission-oreinted toward the purposes of the particular bureau or department involved. Thus, it is evident that building research in the United States is a broad competitive system with major participation by industry, educational institutions, governmental units, and private entrepreneurs. There has been no comprehensive plan for conducting research or for solving major problems in the building industry, and there is no organized system for coordinating the results of the existing highly fragmented and dispersed research activity. Standardization of building practice at the national level is carried out by a paid staff, highly inadequate in size, supplemented in a major way by essentially volunteer technical personnel, often tacitly subsidized, from industry, government, educational institutions and private laboratories. Research in fire safety and architectural acoustics falls into this diversified pattern of organizational sponsorship described above in which the principal objective of the organization is product development, education, or some objective other than the effective integration of building functions.

The protection of life and property was one of the earliest concerns of man when he began to provide habitation for himself, and was, therefore, the subject of some of the eariest building regulations. However, fire protection requirements in a building tend to restrict freedom in architectural and aesthetic design and the choice of materials. Thus, the fire requirements tend to be met grudgingly and marginally in building design and usually do not constitute a part of the customer appeal. Furthermore, since fire regulations are legally binding in most cities, compliance of a building product must be determined by test and the properties of the product must be carefully described for identification. Proof of compliance thus represents a significant expense for the manufacturer, and often constitutes a source of contention between the manufacturer and the regulatory officials. Furthermore, if a new building product or subassembly involving significantly different principles or properties is designed by a manufacturer, the task of obtaining proof of compliance is frequently made more difficult, time-consuming, and expensive because the testing agency has to develop a new test procedure for evaluation. Likewise, if an improvement in testing procedures is devised through research or experiment, the organizations responsible for certification of compliance feel that all previously certified materials must be retested using the new test procedure to protect themselves and the public. Such an unscheduled retesting program represents additional cost to the manufacturer and added laboratory expense and administrative complexities in the testing laboratory. Thus, neither the manufacturers of certified products, nor the certifying laboratories, nor the municipal regulatory officials, strongly encourage the introduction of new building products, new concepts in fire protection, and new evaluation techniques, since these activities complicate the smooth functioning of the total certification system. For the reasons cited above, fire research is not a commercially attractive activity for building component manufacturers nor an administratively or financially attractive program for the certification laboratories.

Noise control in buildings is becoming an increasingly important requirement because of changing construction practices and the rapid expansion in the use of powered equipment both inside and outside of buildings. It is not unusual for a medium-income family to have 15 to 20 electrical motors in their house driving a dozen blowers or pumps, each with a potential for undesirable noise generation. Concurrently, the use density of automobiles, trucks, buses, and aircraft has increased in and around the cities. At the same time, an increasing use of glass and lightwieght wall construction has occurred in both commercial and residential construction. Thus, the multiplication of noise sources and the extensive use of acoustically transparent materials in modern buildings produces increased demand for acoustic treatment in buildings.

Adequate fire safety and satisfactory acoustic environment in a building are both system problems of great complexity. In each case a satisfactory solution depends on the nature of the structural frame of a building, the properties of the materials of construction, the methods used to join them together, the size and shape of the enclosed spaces, the location and size of openings between rooms, the size and location of windows, the furnishings placed in the rooms, and the quality of workmanship employed in assembly. In addition, the fire safety is affected significantly by the potential for horizontal and vertical air movement through a structure. Thus, it is seen that the responsibility for adequate design cannot be assumed by the manufacturer of materials alone, nor fully by the architect, since the quality of the work of the builder also influences the end result. The number of parameters affecting fire safety and acoustical control are so numerous and their interrelationship in a building so complex that, in the present state of development of building science, the fundamentals of the design problem are not fully understood by anyone. In addition, there is a significant degree of incompatibility between the means for providing fire safety and noise control. Many of the materials that have good sound absorption properties do not have good fire and flame spread resistance. Furthermore, materials that have good acoustical absorption tend to retain surface soiling because of their texture and are more costly to maintain. In consequence of the complexities cited above, there is a need for a focus of leadership for research in fire safety and architectural acoustics that transcends the limited responsibility of each of the participants in the building construction process and that is responsive to the needs of the occupant rather than the commercial interests of the individual enterprises in building construction.

The warranty or guarantee on workmanship and materials in a building covers a period ranging from about one year to five years for most components. Thus, the expected useful life of the building and the equipment installed in it, exceeds the guarantee by a factor ranging from about 5 to 50 for various elements. Therefore, the responsibility of the builder and designer expires, within the context of presnet practice, long before the purchaser has realized his value from the building. The whole appeal of building as an investment depends on the building having a significant residual value after it has been completely paid for. Thus, the importance of the long-term durability of building materials is of central importance to the owner.

Raw materials used in building construction are typically modified and improved in a factory as they are formed into building products by processes of purification, shaping, molding, surface treatment, modification of composition, burning, chemical treatment, etc. These factory processes usually improve the strength, appearance, or durability of the product. However, gradual depletion of these properties begins as soon as a building is exposed to outdoor climatic factors and to the effects of use, and in some cases deterioration begins during construction or even before the material is purchased.

Causes of deterioration of buildings from climate-related phenomena include settling or heaving of the earth beneath a building; expansion and contraction resulting from changes in temperature and humidity; the effects of wind, sun, rain, hail and temperature on building materials; and corrosion and other chemical and physical changes in the properties of materials caused by moisture, particulates, and other contaminants in the atmosphere. Rates of deterioration vary with the properties of natural materials, the quality of the factory treatment, the severity and variability of the climate, the characteristics of the earth at the site, and the amount of contaminants in the air. The rate of deterioration cannot be detected for several years under natural conditions. Many natural materials contain varying amounts of impurities or are so complex in composition that the chemical or molecular processes involved in deterioration are not well understood and have not thus far been adequately reproduced in the laboratory. The effect of trace elements or contaminants in the atmosphere over a long period of time is difficult to evaluate by accelerated testing procedures. Furthermore, there are interactions between the various causes of deterioration in buildings. For example, physical movement of a building caused by earth settlement or expansion and contraction of the building itself often produces changes in moisture penetration to the inner elements of a wall which in turn affect corrosion, spalling and biological deterioration of materials.

Most specifications for building materials and most of the acceptance tests for buildings and building components are based on their characteristics when new. Only limited progress has been made, and that often in a particular class of materials, in predicting or measuring the useful life of materials based on accelerated laboratory tests. This is regarded as resulting from incomplete understanding of the processes of deterioration, inadequate simulation of the real-life process in the laboratory, or inability to correlate an accelerated laboratory procedure with the deterioration of the same material in a real-time scale and natural exposure. This inadequacy in the ability to measure durability with sufficient assurance in accelerated laboratory tests probably accounts for a part of the unfavorable ratio, from the users' standpoint, between the warranty or guarantee period and the expected useful life of most building components.

The Building Research Division of the National Bureau of Standards has been and is continuing to develop laboratory procedures for rapid evaluation of deterioration of building components; it has recently activated exposure sites in areas of differing climate for study of natural exposure of small samples of building materials; and it is engaged in a detailed study of the less obvious factors of outdoor environment that affect the deterioration of building materials. It is considered essential, therefore, to supplement these studies with investigations of deterioration in a full scale structure under natural climatic conditions and in a real-time scale for correlation with the above-mentioned laboratory and exposure data.

CHAPTER 8

Recommendations

Because of the diversified character of the building construction industry, its incomplete evolution from a craft industry, the interdisciplinary character of research in fire safety, architectural acoustics and climate-induced deterioration, and the fact that research in these building characteristics appears to benefit the user or owner of buildings more specifically than manufacturers, as described in Chapter 7, the following recommendations for program and facilities are made:

1. That an experimental building of about 5000 ft^2 floor area, as described in Chapter 3, be constructed at the NBS Gaithersburg site as soon as possible, to study the interaction of the weather, the earth, and the service-imposed environmental systems under actual use conditions of time, size, and environment. These studies will complement a dozen or more studies of similar phenomena already completed or in progress under laboratory conditions to provide reinforced recommendations for test procedures and criteria for evaluation of durability of building systems.

2. That an architectural acoustic facility of about 28,000 ft^2 floor area, as described in Chapter 4, be constructed at the NBS Gaithersburg site as soon as possible, incorporating sound transmission rooms, a reverberation chamber, an anechoic room, a psychoacoustics laboratory, a simulated field-test structure, and other auxiliary laboratories and offices to serve as a focus of leadership for the development of technical information and test methods that can be used in standards related to sound transmission, sound absorption, and structure-borne sound in buildings and the various mechanical and electrical equipment used in buildings.

3. That the Fire Center at the National Bureau of Standards take cognizance of the total needs of the nation for fire research and engineering, fire safety, and information, as described in Chapter 5.

4. That the Fire Center be provided, in one or more phases of construction, with the buildings and facilities described in Chapter 5 for carrying out fire research and engineering studies on ignition, fire growth, combustion products and life safety, fire characterization of materials, fire performance of building systems, fire detection and suppression human factors in fire situations, and to provide offices for personnel who coordinate, monitor,

or contract for fire research or information and training services with other organizations.

5. That land be purchased at a site remote from Gaithersburg to carry out fire research on full-scale buildings if the smoke generation of the experiments exceeds that permitted by air pollution limitations at the Gaithersburg site.

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